ONTARIO DEPARTMENT OF EDUCATION

CURRICULUM G.S-27C

INDUSTRIAL PHYSICS CURRICULUM GUIDE

FIVE-YEAR PROGRAM

GRADES 11 AND 12

1968

USE OF THE CURRICULUM GUIDE

This envelope contains a teacher's guide that expands Industrial Physics, Curriculum G.S-27C. The additional direction will assist the teacher in his definition of the course; however, he is under no compunction to consider the guide as mandatory subject content.

The Divisions and Units are designated at the top of each chart. Beginning at the left-hand side, the Sections and associated Topics are printed within the coloured areas in such a way that the Topics relating to a given Section are actually in contact with the latter by means of the colour pattern. All Divisions, Units, Sections and Topics are identical to those that appear in Curriculum G.S-27C. Note that (O) indicates optional material.

The "Elements" column continues the analytical breakdown beyond the Topics level. It completes the exploded-view concept in which each Division is analyzed in a series of five steps, each step representing a dissection of the former. Thus, Section content is made explicit by its associated Topics, and each Topic is made explicit by its associated Elements.

A numbering system is used to designate each subdivision of the course. It is organized in such a way that, reading from left to right:

- The first number indicates the Division
- The second number indicates the Unit
- The third number indicates the Section
- The fourth number indicates the Topic
- The fifth number indicates the Element

As an example of this arrangement, 1132.1 refers to Division 1, Unit 1, Section 3, Topic 2, and Element 1. The number of digits denotes the degree of breakdown: as a case in point, 32.2 indicates Section 2, Unit 2 of Division 3.

Although each Unit, Section, and Topic is developed in a logical manner, **no attempt has been made to divide the course into "lessons", nor does the Guide provide the teacher with a chronological sequence.** Since the course, which covers both Grades 11 and 12, is treated as a two-year entity, the arrangement of subject material into a weekly, monthly, and yearly sequence is the task of the teacher. It is hoped that he will be able to shape the subject material into a cohesive pattern in which interrelationships and principles are stressed.

The "Cross-Reference" column utilizes the numbering system to facilitate integration of the course as a whole. Many but by no means all of the possible cross-references have been listed. Undoubtedly the teacher will add or delete according to his own perspective. The numbers do not necessarily correspond to the element which appears in the same horizontal line; rather, the numbers relate to the topic with which they are associated. No precise alignment was possible.

The "Fundamentals" column contains the basic concepts and principles which make the study of Industrial Physics a formative educational experience. This column is an attempt to generalize from the particular Section, Topic and Element material; it is **not** a further breakdown of the Elements. Concepts, principles, laws, and rules are included, along with the relevant mathematical expressions. Obviously, if a student gains a clear grasp of these fundamentals, he will possess a sound foundation for further study in the physical sciences.

The concepts that have a (C) after them are those which have broad applications in several disciplines or fields. For example, "feedback" occurs in a wide range of physical and social contexts.

The "Technical Terms" column consists of a list of those technical terms that the students must understand in order to grasp the topic under consideration. Many of these items need to be formally defined; others may only require familiarity on the part of the student.

In the coloured vertical column on the right, student activity of several kinds are suggested. These refer to those activities which the student performs without direct supervision, and frequently include the use of hardware. The letter (E) after the title indicates an experiment which is to be done; the letter (X) denotes problem-solving periods devoted to calculations done on paper; the letter (A) refers to an "application-study" in which the student is directed to scrutinize an industrial application or applications, particularly as to design features; the letter (P) designates a project of some kind. Although the latter kind of activity does not appear frequently in the Guide, it is hoped that teachers will encourage their students to embark upon major projects of a kind which involves several of the Divisions: such projects provide a valuable integrating experience and relate to "real-life" situations more closely than isolated experiments.

Note that the student activity in a Five-year course should utilize at least fifty per cent of the time available. Skillful teaching in which the inductive approach is emphasized should increase this ratio considerably. Whatever the methods, comprehension and interest should be fostered even at the expense of content.

The "Discussion" column is an attempt to enable the curriculum committee members to communicate information relevant to the parallel material, if it has not been conveyed on the remainder of the chart. Items are clarified or emphasized, and further suggestions made to the teacher.

INDUSTRIAL PHYSICS G.S-27C

DIVISION ONE: MECHANICS AND MATERIALS

UNIT: 1.1 Introduction to Mechanics

Columns: Element | Cross-reference | Fundamentals | Technical Terms | Student Activity | Discussion

11.1 Types of forces

Estimated periods: 2T, 4SA

111.1 Non-contact forces

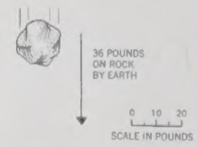
Element	Cross-reference	Fundamentals	Technical Terms
1111.1 Magnetic	411.1	A force is that which changes the motion of an object	Attraction, repulsion
1111.2 Electric	411.2 411.3		North and South poles Positive and negative charges
1111.3 Gravitational			Weight

111.2 Contact forces

Element	Cross-reference	Fundamentals	Technical Terms
1112.1 Tensile	13.1	A force is exerted **by** something **on** something	Tension
1112.2 Compressive	13.2	A force acts in a specific direction	Compression
1112.3 Shearing	13.3		Shear
1112.4 Bending	13.5		Bending
1112.5 Twisting	13.6		Torsion
1112.6 Friction			Friction

111.3 Description of a force

Element	Cross-reference	Fundamentals	Technical Terms
1113.1 Characteristics		A force has magnitude has direction is exerted on A is exerted by B	Example of description of force: F on A by B = 36 lb (down)
1113.2 Effects	122.2	A force always causes A to experience a change in motion (if the force is acting alone)	
1113.3 Units		The magnitude of a force is expressed in terms of pounds, tons, etc.	
1113.4 Representation	1121.2	A force may be represented by an arrow, its length representing the magnitude and its arrowhead the direction	



111.4 Combined forces

Element	Cross-reference	Fundamentals	Technical Terms
1114.1 Unbalanced	122.2	If the forces on a stationary object become unbalanced it will move — i.e. an unbalanced force system causes motion change	Unbalanced force system Dynamics
1114.2 Balanced	114.2 1132.2	If the forces on a stationary object remain balanced it will not move — i.e. a balanced force system causes no motion change	Balanced force system Statics

Student Activity

DISCOVERY OF A FORCE DETECTOR (E)
To discover **how we know** that a single force exists. e.g. The action of (a) a magnet on a nail at rest, (b) a charged rod on a very fine stream of water flowing from a tap, (c) an electromagnet on a stationary armature, (d) the earth on a wood block when released above the floor.

VERIFICATION THAT A FORCE CAUSES MOTION CHANGE (E)
e.g.
(a) Pull chewing gum
(b) Compress foam rubber
(c) Shear plasticene
(d) Bend metre stick
(e) Twist plastic ruler
(f) Bring sliding block to rest by desk top.

DIAGRAMMATIC REPRESENTATION (X)
Drawing and labelling of arrows to represent some of the forces encountered in the above experiments.

COLLINEAR FORCES (E)
Discovery of the condition necessary, when two or more collinear forces act on an object, to produce (a) a change in motion, (b) no change in motion. e.g. A cart is held in a fixed position. Two or more spring balances are attached to opposite ends. The cart is released and change in motion noted.

DRAWING OF FORCE DIAGRAMS (X)
Related to above experiment.

Discussion

This section should consist of a very elementary treatment of the concept of force. A single (unbalanced) force always changes the motion of a mass. The motion change acts as a force detector. Simple motion changes are starting from rest, coming to rest, direction change, etc. Reference to acceleration, Newton's second law, multiple force systems, etc., should be reserved till later.

The student should be encouraged to discover how we know that gravitational, magnetic and electric forces act. These forces, if acting alone, will change motion. Balance out irrelevant forces. For example, let a magnet pull horizontally on a nail lying on the desk, so that the earth's pull and the desk's push balance out. In all cases the student should observe the common factor, that of motion change. Students should recognize what each force is exerted by and on.

Direction and magnitude may be referred to in passing but a vector treatment will come later.

Avoid reference to the poundal and newton at this stage. Avoid a formal definition of force in terms of mass and acceleration.

The treatment of force should now be extended to systems involving two or more forces. Consider collinear forces only in this section. It is suggested that initially the object (say, a dynamics cart) be at rest and that force systems be considered as balanced or unbalanced according to the resulting change in motion, if any, when the force system is applied.

11.2 Vector analysis of forces

Estimated periods: 5T, 5SA

112.1 Scalars and vectors

Element	Cross-reference	Fundamentals	Technical Terms
1121.1 Scalar	414.1 1211.4	A scalar quantity has magnitude only. It is expressed by a number and a unit.	Scalar quantity Scalar
1121.2 Vector	**1113.4** 1211.5 4141.3	A vector quantity has magnitude and direction. It is expressed by a number, a unit and a direction.	Vector quantity Vector

112.2 Combination of vectors

Element	Cross-reference	Fundamentals	Technical Terms
1122.1 Experimental determination of resultant	4141.4	Parallelogram of forces	Equilibrant Resultant Parallelogram of forces
1122.2 Graphical determination of resultant	414.7 1141.2	Triangle of forces Polygon of forces	Triangle of forces Polygon of forces
1122.3 Mathematical determination of resultant	4147.3	Resolution of a force F into its x and y components. $F_x = F\cos\theta$, $F_y = F\sin\theta$. Pythagorean addition to find resultant's magnitude $R = \sqrt{A^2 + B^2}$ where A and B are sums of x and y components and R is magnitude of the resultant. Direction of resultant is given by $\tan\theta = B/A$	The sine, cosine and tangent of an angle. Resolution of a vector. Components Angle θ of inclination of resultant Pythagorean relation

Student Activity

VECTORS (X)
Drawing of a few vectors, to scale, of forces from worded descriptions.

RESULTANT (E)
Determination of equilibrant of two non-parallel forces: hence method for finding the resultant.

VECTOR PROBLEMS (X)
Drawing of scale diagrams, using parallelogram or triangle of forces to determine the resultant. Extend to polygon of forces.

APPLIED MATHEMATICS (X)
Review of the primary trigonometric ratios. Determination of the x and y components of a force — simple problems. Solution of problems involving the addition of forces by the method of components using the Pythagorean relation.

Discussion

Some examples of scalars and vectors may be mentioned, but not studied in depth here. Scalars — mass, volume, density, time, temperature, cost, energy.

Vectors — force, displacement, velocity, momentum.

Concept of force is now extended to addition of non-parallel coplanar forces to obtain a resultant. This should be developed from experimental data, then treated through scale drawings working up to a mathematical solution.

Exercises should relate to practical situations wherever possible.

Do not use the cosine law. Consult the Mathematics Department regarding work done by students in trigonometry. Recall or teach the primary ratios and the use of trigonometric tables. Most of the problems should be restricted to two or three, possibly four, forces.

11.3 Turning effects of forces

Estimated periods: 3T, 5SA

113.1 Moments and couples

Element	Cross-reference	Fundamentals	Technical Terms
1131.1 Moment of a force	13.4 13.5 13.6 3131.3 3131.4	Moment M = Fd where d ⊥ F. The moment of a force equals the sum of the moments of its components. Torque, a special case of moment, generally produces rotation about an axis.	Moment M Line of action of force F Moment arm d Component Axis of rotation Torque lb-ft, kg-metre, etc.
1131.2 Couple		A couple is a pair of equal but opposite forces separated by a distance d. The sum of the forces = 0 The sum of the moments = Fd	Couple Σ — notation: $\Sigma F = 0$ $\Sigma M = Fd$

113.2 Principles of moments

Element	Cross-reference	Fundamentals	Technical Terms
1132-1 Condition for **no** rotation	**1114.2** 114.2	In a balanced system the sum of the moments is zero. $\Sigma M = 0$	Equilibrium Principle of moments Relational convention — clockwise and counterclockwise moments have opposite signs.
1132.2 Centre of gravity of a uniform beam	114.1	The weight of a uniform beam may be considered to act at its mid-point.	Centre of gravity

Student Activity

MOMENT COMPONENTS (X)
Discovery of the relation between the moment of a force and the moments of its components.
Solution of simple problems on a moment, its components and the sum of similar moments.

DISCOVERY OF THE RESULTANT (X)
(a) of forces (b) of moments, involved in a couple.

PRINCIPLE OF MOMENTS (E)
Discovery of the principle of moments as applied to a horizontal beam supported at the centre: include some upward forces.

WEIGHT OF A BEAM (E)
Discovery of the fact that the entire weight of the beam may be considered to act at its mid-point.

MOMENTS PROBLEMS (X)
Solution of problems on moments of forces vertical on horizontal beams.

Discussion

Define the moment of a force and allow students to find some properties of moments and couples by means of a graphical exercise. Here it is unnecessary to make a fine distinction between moment and torque.

Although a couple is not a moment it is worth stressing that a couple has the rotational effect of a moment.

Use F.P.S. and M.K.S. units.

Here students might balance a beam, list the moments without regard to sign, and discover that sum of clockwise = sum of counterclockwise.

Students could weigh and balance the beam (with pivot near one end), then using the principle of moments determine where the weight is acting. Extend the principle to cases where the beam has several supports.

11.4 Equilibrium of forces

Estimated periods: 4T, 6SA

114.1 Free body diagrams

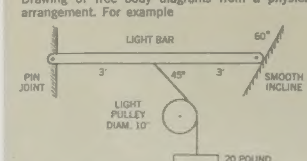
Element	Cross-reference	Fundamentals	Technical Terms
1141.1 General aspects of diagrams	**1132.2**	Pictorial representation of where and how forces act on a body. Some forces are exerted by a remote object, e.g. gravity by the earth. Some forces are exerted by an object in contact, e.g. pull by a cable or reaction by a surface.	Free body diagram Remote force Contact force
1141.2 Particular aspects of diagrams	**112.2**	Diagrams should indicate convention of signs and all given data, e.g. dimensions, magnitudes and directions.	Convention of signs
1141.3 Special force considerations	**1132.2**	(a) The weight of an object acts down from its centre of gravity. (b) Tensile forces have equal magnitude throughout a single cable. (c) Reactions at smooth surfaces are normal to the surface. (d) Reactions at pin joints should be treated in terms of two rectangular components.	Reaction force Normal force Tensile force (tension) Weight (pull of Earth) Smooth = frictionless Light = weightless

114.2 Conditions for equilibrium

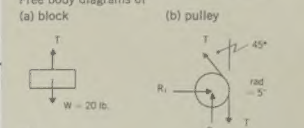
Element	Cross-reference	Fundamentals	Technical Terms
1142.1 Prevention of translation		Sum of forces is zero	$\Sigma F = 0 \begin{cases} \Sigma F_x = 0 \\ \Sigma F_y = 0 \end{cases}$
1142.2 Prevention of rotation		Sum of moments is zero	$\Sigma M = 0$
1142.3 Necessary and sufficient conditions for equilibrium	**1114.2**	The sum of the forces and the sum of the moments are both zero.	$\Sigma F = 0$ and $\Sigma M = 0$

Student Activity

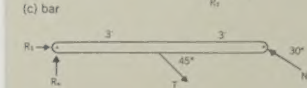
FREE BODY DIAGRAMS (X)
Drawing of free body diagrams from a physical arrangement. For example



Free body diagrams of
(a) block (b) pulley



(c) bar



W = weight
T = tensile force
R = reaction force
N = normal force

CONDITIONS FOR EQUILIBRIUM (E)
Determination of forces acting on a physical system, using pulleys, weights, spring balances, etc.

SOLUTION OF EQUILIBRIUM PROBLEMS (X)

Discussion

The construction of good free-body diagrams is perhaps the most important single step in the solution of mechanics problems.

A number of simple examples should be selected with care to enable the student to recognize forces and represent them clearly and accurately.

Some examples should be taken from actual physical arrangements if possible. At first it might be well to concentrate on the free-body diagrams without reference to the mathematical relations governing equilibrium.

A careful sequence of problems from easy to difficult must be given. Avoid three dimensional cases. Time will not permit force analysis of truss structures of cases involving frictional components.

UNIT: 1.2 Dynamics

Topic	Sub-topic	Element	Cross-reference	Fundamentals	Technical Terms
12.1 Kinematics (Estimated periods: 3T, 9SA)	121.1 Rectilinear motion			Linearity (C)	
		1211.1 Uniform and variable		Rectilinear motion; translation	Kinematics; Rectilinear motion; Translational; Plane motion
		1211.2 Distance and displacement		Distance; displacement	Distance, displacement; Scalars, vectors
		1211.3 "s-t" graph		Displacement depends on time	Units — FPS, MKS; Slope of curves
		1211.4 Speed and velocity	112.1, 1212.2	Average velocity $v = \frac{\Delta s}{\Delta t}$	Δ = change in resultant and variable velocities
		1211.5 Velocity problems			
		1211.6 "v-t" graphs		$s = \frac{1}{2}(u + v_f)t$; $s = \frac{(v_f - u)t}{2} + ut$; s = area under curve	Initial velocity (u); Final velocity (v_f)
		1211.7 Acceleration	122.2, 1212.3	Average acceleration $a = \frac{\Delta v}{\Delta t}$	Units of acceleration:
		1211.8 Acceleration problems		$v_f = u + at$; $s = ut + \frac{1}{2}at^2$; $v_f^2 = u^2 + 2as$	feet/sec², meters/sec²
	121.2 Curvilinear motion				Curvilinear
		1212.1 Angular displacement	136.2	Angular displacement — θ	θ = angle in radians
		1212.2 Angular velocity	133.2	Angular velocity $\omega = \frac{\Delta\theta}{\Delta t}$	Angular velocity (ω)
		1212.3 Angular acceleration	1211.4	Angular acceleration $\alpha = \frac{\Delta\omega}{\Delta t}$	Angular acceleration (α)
		1212.4 Normal acceleration	1211.7	Normal acceleration $a_n = \frac{v^2}{r}$	Normal acceleration (a_n)
12.2 Newton's Laws (Estimated periods: 2T, 6SA)	122.1 The First Law	1221.1 Inertia defined	123.1, 123.2	Inertia	Inertia; Sigma Σ = sum of
	122.2 The Second Law	1222.1 Unbalanced force	1113.2	$F = ma$	Poundal, pound, Newton
		1222.2 Force-formula and units	114.1	$W = mg$	Mass and weight
		1222.3 Weight and mass	1211.7	$F = \frac{W}{g}a$	Mass in slugs $\left(\frac{W}{g}\right)$
		1222.4 Engineering units	141.1	$F_n = ma = \frac{mv^2}{r}$	Centripetal force
		1222.5 Normal force		$= \frac{W}{g}\frac{v^2}{r}$	Centrifugal force
	122.3 The Third Law	1223.1 Action and reaction relationships		$F_{A\ on\ B} = -F_{B\ on\ A}$	
	122.4 Momentum and impulse	1224.1 Momentum	1211.4	$M = mv$	Momentum
		1224.2 Impulse	1222.3	Impulse $= F(\Delta t)$	Impulse
		1224.3 Units of momentum and impulse		$F = \frac{m(v - u)}{\Delta t}$	
		1224.4 Rate of change of momentum			
12.3 Dynamic equilibrium (0) (Estimated periods: 1T, 3SA)	123.1 Inertial forces in rectilinear motion	1231.1 Meaning of inertial force	1221.1	$F_i = \frac{W}{g}a$	Inertial force (F_i)
		1231.2 Simple problems	121.1		
	123.2 Inertial forces in curvilinear motion	1232.1 Problems involving normal force	1221.1	$F_i = \frac{W}{g}\frac{v^2}{r}$	Normal component of force
		1232.2 Problems involving tangential force	121.2		Tangential component of force $\frac{\Delta\omega}{\Delta t}$
12.4 Energy and power (Estimated periods: 4T, 4SA)	124.1 Work	1241.1 Concept of work	412.3	$E = (F\cos\theta)s$	Work (E)
		1241.2 Units of work	2142.1	$E = Fs$	Energy; power
		1241.3 "F-s" graph		E = area under curve	Joule; Newton-meter
	124.2 Potential and kinetic energy	1242.1 Definition of each form of energy	2142.3	$E_p = Wh$	Potential energy (E_p)
		1242.2 Conservation of energy	2142.2, 225.2, 214.3, 4221.5, 4144.2	$E_k = \frac{mv^2}{2}$ $= \frac{Wv^2}{2g}$	Kinetic energy (E_k)
		1242.3 Energy losses		Conservation of energy; $E_k + E_p$ = constant	
	124.3 Power and efficiency	1243.1 Definition of power	412.3	$P = \frac{E}{t}$	Power
		1243.2 Units and equivalents	2142.1, 4221.5, 4222.4, 4222.7, 4223.5, 2242.2	1 H.P. = 778 ft. lb/sec = 746 watts	Horsepower; Watt; Joule/second
		1243.3 Definition of efficiency		Efficiency $(\eta) = \frac{\text{output}}{\text{input}}$	Efficiency (η)

Topic	Student Activity	Discussion
12.1 Kinematics	**DISPLACEMENT (X)** Determination of resultant displacement by graphical and mathematic methods. **DETERMINATION OF VELOCITIES (E)** Use tapes and timers. **DISPLACEMENT-TIME GRAPHS (X)** Plot s-t curves from given data and obtain velocity from slope. **RESOLUTION OF VELOCITIES (X)** Obtain acceleration from the slope of v-t graphs and displacement from area. **GRAVITATIONAL ACCELERATION (E)** Determine "g" using tapes and timers. **SIMPLE CURVILINEAR MOTION PROBLEMS (X)**	In the introduction to the Unit on Dynamics, the difference between kinematics and kinetics, particles and bodies should be fully explained. When introducing distance and displacement, use examples to give the students a clear understanding of the difference between scalar and vector qualities. When dealing with graphs, stress the choice of scales and conventions. Dependent and independent variables should also be mentioned. Stress the difference between average and instantaneous values and the significance of slopes of curves and areas under curves. In dealing with velocities, mention mach numbers. During discussion of units, conversion from mi/hr to ft/sec should be attempted. The MKS system should also be mentioned, but problems involving conversion of ft/sec or mi/hr to MKS should be avoided. Formulae should be developed where possible. When dealing with acceleration, establish retardation as negative acceleration. The radian as a scientific measurement of angle should be defined. Problems should be assigned converting degrees to radians and converting rer/min to radians/second. Problems involving angular acceleration should be simple in nature and should lack too much emphasis. If time permits, the teacher may wish to demonstrate the determination of angular acceleration using a falling weight.
12.2 Newton's Laws	**INERTIA EXPERIMENTS (E)** **SIMPLE PROBLEMS INVOLVING INERTIA (X)** **CONSERVATION OF MOMENTUM (E)**	Newton's First Law can be explained: If the velocity of a body is zero or constant, then the sum of the forces acting on the body is zero. The resisting property of a body to change its state of motion is inertia. Normal force may be established by substituting $a_n = \frac{v^2}{r}$ into the formula $F = ma$. Avoid involved discussion of centripetal and centrifugal forces and acceleration, although the recognition of these forces is important. The Third Law has so many cross-references that all were omitted. When dealing with impulse and momentum, it should be explained that Newton's Second Law of motion must be modified; i.e., $F = ma$ becomes $F(\Delta t) = m(\Delta v)$. Angular impulse and momentum should only be discussed if time permits.
12.3 Dynamic equilibrium (0)	**PROBLEMS INVOLVING THE CONCEPT OF INERTIAL FORCE (X)** **SIMPLE PROBLEMS (X)**	By using "inertial force", an unbalanced system may be treated as a statics problem.
12.4 Energy and power	**FORCE-DISPLACEMENT (E)** Experiment to show work done; plot F-A graphs. **POWER-EFFICIENCY (X)** Problem involving power and efficiency.	Establish difference between work, energy and power. Use engineering units. The pendulum is frequently used as a convenient illustration of energy conversion and conservation. It should be pointed out when discussing efficiency that output is equal to input minus losses.

INDUSTRIAL PHYSICS G.S-27C

DIVISION ONE: MECHANICS AND MATERIALS

UNIT: 1.3 Introduction to Statics

Section	Topic	Element	Cross-reference	Fundamentals	Technical Terms	Student Activity	Discussion
13.1 Tensile force *Estimated periods: 4T 3SA*	131.1 Deflection	1311.1 Proportional 1311.2 Non-proportional 1311.3 Hooke's Law 1311.4 Proportional limit	1112.1 3312.3 3112.4	Proportionality (C) $F = K\delta$ Hooke's Law Linearity (C)	Deflection (δ) Tensile Tension Elastic action Proportional limit Yield point	**ELONGATION (E)** — spring — rubber — plastic rod — steel wire • Compare spring when load increases — does deformation increase in same proportion? • Show with plastic that same linearity occurs but different constant. • Show again with same length but areas as 2x, 3x first test — "stress". • Show again with same area but length as 2x, 3x of first test — "strain". • Use wide sheet of thin rubber to show Poisson's Ratio — contraction laterally upon pull.	This whole section should be treated as a long experiment with the emphasis on self-discovery of the behaviour of materials. Use "weak" materials which will show deformation to the eye. Then pose question for steel — does it behave in same way? Stress should be approached from free body diagrams as well as unit of external force per unit of cross-sectional area. The use of more sophisticated measurement devices should be postponed until the next Unit (Unit 1.4 Materials). Note the similarity of topic, element, fundamentals, for each of the first three sections in this unit.
	131.2 Strain	1312.1 Direction and magnitude 1312.2 Units 1312.3 Poisson's Ratio	3112.4	$\epsilon = \frac{\delta}{L}$ Deformation is parallel to force Strain in one direction induces strain in other directions	Longitudinal deformation Lateral deformation Unit strain (ϵ)		
	131.3 Stress	1313.1 Direction and magnitude 1313.2 Units	213.1 311.1	$\sigma = \frac{F}{A}$	Normal stress (σ)		
	131.4 Interrelationships	1314.1 Modulus of elasticity	1334.1 1352.3	$E = \frac{\sigma}{\epsilon}$ $E = \frac{FL}{A\delta}$	Young's modulus — modulus of elasticity (E) Resilience		
13.2 Compressive force *Estimated periods: 3T 3SA*	132.1 Deflection	1321.1 Proportional 1321.2 Non-proportional 1321.3 Hooke's Law 1321.4 Proportional limit	1112.2 3312.3 3112.4	$F = K\delta$ Emphasize same pattern as in tension, but opposite sign	Compression Compressive Elastic action Elastic limit Instability	**COMPRESSION (E)** — spring — plastic — wood Sequence of tests with same pattern of variables as was used for tension preferably using the same materials. **COMPRESSION TESTS (E)** • Compression test on wood, different lengths. • Compression on block of rubber or porous plastic.	Repeat **same** sequence of demonstration tests as in tension, with same emphasis on self-discovery. (Plastic is ideal material for the continuity.) Same comments as 13.1. Note the similarity of topic-element-fundamentals for each of the first sections in this unit. In each sequence, emphasis should be on self-discovery by the students. "You can't push on a rope."
	132.2 Strain	1322.1 Direction and magnitude 1322.2 Units 1322.3 Poisson's Ratio	3112.4	$\epsilon = \frac{\delta}{L}$ Deformation is parallel to force Strain occurs parallel and normal to force direction	Longitudinal deformation Lateral deformation		
	132.3 Stress	1323.1 Direction and magnitude 1323.2 Units	213.1 311.1	$\sigma = \frac{F}{A}$	Normal stress		
	132.4 Interrelationships	1324.1 Modulus of elasticity	1334.1 1352.3	$E = \frac{\sigma}{\epsilon}$ $E = \frac{FL}{A\delta}$			
13.3 Shear force *Estimated periods: 3T 1SA*	133.1 Deflection	1331.1 Proportional 1331.2 Non-proportional 1331.3 Proportional limit	1112.3 135.4	$F = K\delta$ Hooke's Law		**SHEAR TESTS (E)** Apply parallel forces to large block of porous plastic or rubber — reduce thickness in stages but show that angle will be a constant. ("Pack of cards" analogy.) Then use model of a riveted connection, model of simple roof truss where shear develops at support, shearing action of nails and bolts.	Draw analogy with rivets (and show with cross section through riveted joint). Show that shear occurs in nailed joint and a joint in the timber roof truss. Rubber in shear-isolation mounts. Do **not** try to develop a too complicated analysis of shear on oblique planes, or shear developed due to a normal stress.
	133.2 Strain	1332.1 Direction and magnitude 1332.2 Units	3112.4 1212.1	$\gamma = \frac{\delta}{L}$ Deformation is parallel to force	Shear strain (γ) Tangential stress per unit of area Strain can be expressed in radians		
	133.3 Stress	1333.1 Direction and magnitude 1333.2 Units	213.1 311.1	$\tau = \frac{F}{A}$	Shear stress (τ)		
	133.4 Interrelationships	1334.1 Modulus of rigidity	131.4	$G = \frac{\tau}{\gamma}$	Modulus of rigidity (G)		
13.4 Area relationships (0) *Estimated periods: 4T 4SA*	134.1 First moment of area	1341.1 Distributed loads 1341.2 Concentrated loads	113.1	$X = \frac{\Sigma A_x}{\Sigma A}$ $X = \frac{\Sigma W_x}{\Sigma W}$	Resultant force Centroid or centre of balance Load diagrams	**MOMENTS OF AREA (E)** • Centre of action of forces on simple lever in 113.2 • Allow students to find centre of balance of rectangle, circle, triangle, "I" section. • Combine "lever" example with a group of point forces on an area and allow students to locate centre.	At this stage, do not go into detail about moments of inertia other than those about neutral axis. Don't develop formulas. Simply develop concept as centre of moments from internal forces in a material. Preferably give tables of useful formulae.
	134.2 Second moment of area	1342.1 Rectangle 1342.2 Circle 1342.3 "I" section	113.1	$\Sigma x^2 (\Delta A)$ = Second moment of area	Neutral axis Moment of inertia [($\Sigma x(\Delta W)$] Moment of area [$\Sigma x(\Delta A)$]		
	134.3 Polar moment of area	1343.1 Circle	113.1	$\Sigma r^2 (\Delta A) = J$	Polar moment of area (J)		
13.5 Bending moments (transverse moments) *Estimated periods: 4T 6SA*	135.1 Deflection of a beam	1351.1 Proportional 1351.2 Proportional limit	1112.4	$F = k\delta$	Beam Transverse moment	**DEFLECTION (E)** Students should apply loads to centre of simply supported beam and observe deflection. **FORCE DEFLECTION GRAPH (E)** Will be linear and then non-linear but don't analyse. **CANTILEVER BEAMS (E)** Students should repeat series of tests on simple cantilever beam with following variables: — load — length — moment of inertia — elasticity **STRESS DISTRIBUTION (E)** Rubber-beam model, or actual test on wood shows stress distribution in member. **SHEAR FORCE AND BENDING MOMENT PROBLEMS (X)** Determination of position of zero shear force and maximum bending moment.	Only apply bending moment term to external conditions. "Hooke's Law" for transverse forces. Actual value of "k" depends on geometry, and these can be given to students as numerical result without having to justify each one. Don't derive formula from pure mathematics — only introduce these as concepts, but don't dwell on design applications and details. Make the students realize that the deflection of any beam depends on at least four factors. Do **not** complicate with two fixed ends or yielding supports. For shear force diagrams and bending moment diagrams, the accepted conventions must be used.
	135.2 Force-deflection relationships	1352.1 Length 1352.2 Second moment of area 1352.3 Modulus of elasticity (material) 1352.4 Load	113.1 1314.1 137.1 137.2	$\delta = k\frac{WL^3}{EI}$	Moment of inertia (I)		
	135.3 Bending stress	1353.1 Direction and magnitude 1353.2 Distribution 1353.3 Units	131.3 132.3	$\sigma = \frac{Mc}{I}$	Section modulus Bending stress (σ) Bending moment (M) Distance from neutral axis (c)		
	135.4 Shear force and bending moment diagrams	1354.1 Shear force diagram 1354.2 B.M. diagrams	13.3		Shear force diagram Bending moment diagram		
13.6 Twisting moments *Estimated periods: 3T 3SA*	136.1 Origin	1361.1 Terminology	1112.5		Force and couple	**TORSION EXPERIMENT (E)** Twist simple rubber rod (properly supported) with varying forces and lever arms, then repeat with a solid plastic rod, then with metal. Later, use hollow plastic rod of same size, and solid rods of different diameter. Student self-discovery sequence should be: $\theta = k.T$ $k = \frac{L}{J.G}$ by experiment $r.\theta = L.\delta$ by geometric comparison $\therefore\ r\frac{T.L}{J.G.} = L\frac{\tau}{G}$ and $\tau = \frac{Tr}{J}$	See "Mechanics" on torque. The most obvious example to the student is a torsion bar on a car, or the twist from a gear system. Note that we are **not** getting into horsepower, r.p.m. and related items in detail, but these can always be developed from group discussion in class. Teacher should suggest use of polar moment of inertia and shear modulus.
	136.2 Deflection	1362.1 Angular 1362.2 Linear 1362.3 Elastic limit	113.1 1212.1	$\theta = kT$	Angle of twist (θ) Torque (T) Radians		
	136.3 Strain	1363.1 Direction and magnitude 1363.2 Distribution 1363.3 Units	134.3	$\theta = \frac{T.L}{J.G.}$	Length of shaft (L) Polar moment of area (J) Modulus of rigidity (G)		
	136.4 Stress	1364.1 Direction and magnitude 1364.2 Distribution 1364.3 Units	133.3	$\tau = \frac{Tr}{J}$			
	136.5 Interrelationships	1365.1 Modulus of rigidity	131.4	$\frac{\tau}{r} = \frac{G.\theta}{L}$			
13.7 Failure under load *Estimated periods: 3T 5SA*	137.1 Static loads	1371.1 Yield deformation 1371.2 Creep deformation 1371.3 Buckling 1371.4 Ultimate fracture	135.2 135.4	"A material has failed when it ceases to perform its function."	Yield point Ultimate strength Uniform load Point load Failure Fracture	**DESTRUCTIVE TESTING (E)** Destructive tests with various materials to demonstrate that failure depends upon use and load magnitude.	Students should be asked to review all this Section, to suggest when and how a certain unit fails: • When does a bearing fail? • When does a bowl fail? • When does asphalt pavement fail?
	137.2 Dynamic loads	1372.1 Yield deformation 1372.2 Ultimate fracture	135.2 122.4		Brittle fracture		
	137.3 Repetitive loads	1373.1 Fatigue failure			Endurance limit S-N curve		
	137.4 Stress concentration	1374.1 Change in cross-section 1374.2 Notch effect	131.3 1312.3				

INDUSTRIAL PHYSICS G.S-27C

DIVISION ONE: MECHANICS AND MATERIALS

UNIT: 1-4 Materials

Section	Topic	Element	Cross-reference	Fundamentals	Technical Terms	Student Activity	Discussion
14.1 Types of Properties *Estimated periods:* *4T* *0SA*	141.1 Density	1411.1 Introduction 1411.2 Specific gravity 1411.3 Porosity	142.1 1222.3 2122.1	Materials are distinguished by differences in density.	Mass density Weight density Specific gravity Porosity	**MATERIALS STUDY (A)** Student examination of numerous materials.	The aim in this section is to give the student an overview of the inherent properties of materials and to what extent these may be modified to give them utilitarian value. An examination of the basic structure of materials will show why each has intrinsic properties, and finally what criteria govern the selection of materials. The selection of materials to illustrate the various properties and range of properties on a qualitative basis will be left to the teacher. However, the determination of the properties of a basic material such as steel, on a quantitative basis should be undertaken to give the student the opportunity of learning first hand, some of the numerical values of properties of a commonly used material by the conventional testing methods. The numerical values obtained for steel, can serve as a yardstick for comparison, by the student, of other commonly used materials. Discussion of use of Materials: • Materials used as found. • Materials modified to use. • Material conception dictated by design requirements. In Section 14.1 the teacher should introduce by demonstration and/or discussion the various properties outlined. In Section 14.2 the students will have the opportunity of performing the experiments to determine the range of properties previously discussed in Section 14.1. In the treatment of conductivity in Topic 141.3 the teacher might consider all conductivity phenomena under the general classification of a force-flux relationship. For example, a voltage **"force"** applied to a piece of metal results in an electron **"flux"**. The amount of flux that results is determined by the electrical conductivity, a property of the material. The amount of flux, in this case current flow, is limited by collisions of the electrons with the atoms (only the electrons are mobile). The collisions result in electron energy loss (energy **dissipation**) and heating of the metal. Exactly the same explanation is valid for explaining acoustical transmission of materials. Then, a pressure "force" produces a phonon "flow" and sound.
	141.2 Conductivity	1412.1 Electrical 1412.2 Acoustical 1412.3 Thermal 1412.4 Fluid permeability	412.1 142.2	Varies from complete insulation to maximum conduction. Different materials have different absorption coefficients All materials offer some resistance to flow of heat. The physical structure of a material determines its ability to pass fluids through it.	Resistivity Ions Electrons Atoms, molecules Thermal conductivity factor Reverberations Decibel Conductance (heat)		
	141.3 Thermal	1413.1 Expansion 1413.2 Phase change (change of state)	314.1 142.3 3142.1	Materials expand when heated. The structure of materials can change when heated.	Coefficient of linear expansion Transition of temperature Latent heat		
	141.4 Surface	1414.1 Corrosion 1414.2 Surface treatment	142.4	Some materials corrode more readily than others. Special surface treatments prevent corrosion.	Corrosion		
	141.5 Mechanical	1415.1 Elasticity 1415.2 Plasticity 1415.3 Hardness	142.6	The mechanical properties of a material are dependent on its composition and state.	Elasticity Plasticity Hardness		
14.2 Measurement of properties *Estimated periods:* *0T* *14SA*	142.1 Density	1421.1 Specific gravity of various materials 1421.2 Porosity	1411.2	Different materials have a wide range in each of the various properties. Taking the specific gravity of water as unity, the specific gravity of solids, liquids and composites vary from 22 (iridium) to 0.32 (straw).	Cellular structure	**DETERMINE THE WEIGHT AND VOLUME OF A RANGE OF MATERIALS (E)** For example, lead, iron, brass, aluminum, sintered brass, polyethelene, polyfoam, natural wood and plywood. **EXAMINATION OF POROSITY (E)** Examine the porosity of oilite bearings, sponges, cast iron. **CONDUCTORS AND INSULATORS (E)** Comparison of the electrical conductivity of several materials, including conductors and insulators. **ACOUSTICAL PROPERTIES (E)** Comparison of the acoustical properties of various materials. Suggest a box with a sound source inside and sensing device outside. Materials suggested: wood, glass, pressed board, acoustic tile. **HEAT CONDUCTION (E)** Comparison of the heat conductivity of various materials; for example, copper, aluminum, steel, glass. **FLUID PERMEABILITY (E)** Comparison of the fluid permeability of various materials particularly thin membranes. **LINEAR EXPANSION (E)** Comparison of the linear expansion of various metals. **PHASE CHANGES (E)** Determine the phase changes in materials such as lead, copper when heated and the change in magnetic properties. Simple observation of corrosion. **ELASTICITY DEMONSTRATION (E)** Determine load/deflection relationship on simple beam or cantilever using steel, copper and lucite. **PLASTICITY DEMONSTRATION (E)** Comparison of plasticity of materials; such as, putty, beeswax, modeling clay. **HARDNESS TESTING (E)** Determine the hardness of various materials from talc to diamond (Mohr Scale). Use Rockwell Tester or any similar method.	Absorption heats the absorbing material — thermal conductivity is measured by applying a temperature difference "force" which produces a "flow" of electrons and phonons. Heat absorption of course heats the absorbing material. Permeability of a material to fluid flow is measured by applying a pressure "force". Resistance of the material to the flow results in heating.
	142.2 Conductivity	1422.1 Electrical 1422.2 Acoustical 1422.3 Thermal 1422.4 Fluid permeability	141.2 412.1 4132.2	Conductance is the reciprocal of resistance. Acoustic materials are designed for sound absorption. Thermal conductivity may be defined as the quantity of heat that flows in unit time through unit area and thickness of a material. The rate of diffusion of a fluid under a pressure gradient through a porous material is an indication of its permeability.	Conductance (MHO) Flux Transmission loss Dielectric Phonon Decibel Absorption Isolation Transmittability factor Micron		
	142.3 Thermal	1423.1 Expansion 1423.2 Resistance 1423.3 Phase change	141.3	$L = L_o [1 + \alpha t]$ Metals exhibit phase changes when heated, permitting heat treatment processes to give desired properties.	Coefficient of linear expansion (α) Resistivity		
	142.4 Surface	1424.1 Corrosion 1424.2 Surface finish	141.4 212.1	Corrosion is a destructive attack on metals which may be chemical or electrochemical in nature. Corrosion can be minimized by 1. protective metal coatings (galv.) 2. producing oxides or phosphates on metals 3. protective paints 4. rendering the surface of the metal passive	Anodic reaction Cathodic reaction Cadmium plating Parkerizing Bonderizing Lacquers Paints Varnishes Anodizing		
	142.6 Mechanical	1426.1 Elasticity 1426.2 Plasticity 1426.3 Hardness	141.5 1311.3	The deformation is proportional to the load within the elastic limit. The deformation is non linear beyond elastic limit. Hardness has been variously described as resistance to local penetration, to scratching, to machining, to wear and abrasion and to yielding.	Elastic limit Proof stress Ultimate tensile strength Gauge lengths % elongation % reduction in area creep Rockwell Method Shore scleroscope Brinell hardness number Mohr scale		
14.3 Change of properties *Estimated periods:* *3T* *4SA*	143.1 By composition	1431.1 Variation of carbon in steel; Variation of copper in aluminum; Variation of water in concrete		Properties of a material are altered by: • Chemical composition		**TENSILE TESTING (E)** Tensile tests on low, medium and high carbon steel with the steel at room temperatures. **COMPRESSION TESTING (E)** Compression tests on samples of concrete of varied composition. **METCALFE'S EXPERIMENT (E)** Observe changes in hardness, microstructure and strength on heat-treated medium carbon steel.	For all experiments with concrete, purchase ready-mix in 50 lb. bags, and have samples produced by students. Note that these samples must be small; e.g., 1" x 1" x 3".
	143.2 By heating and cooling	1432.1 Hardening 1432.2 Tempering 1432.3 Annealing		• Thermal effects	Quenching Tempering Cooling rates Critical points Annealing Eutectic		
	143.3 By mechanical processing	1433.1 Hot processes 1433.2 Cold processes		• Mechanical effects	Work-hardening Embrittlement Hot and cold rolling Casting Forging Drawing Extrusion Shot peening		
14.4 Explanation of properties *Estimated periods:* *5T* *2SA*	144.1 Atomic	1441.1 Bonds 1441.2 Primary 1441.3 Secondary	411.1	The properties of a material are dependent upon its inter-atomic bonds.	Covalent bond Ionic bond Metallic bond Molecular bond	**MICROSCOPIC EXAMINATION (E)** Examination of metals under microscope. **ACID ETCHING (E)** Show crystalline structure of various metals revealed by acid etching.	It is important that the student understand that atomic structure determines the properties of all materials. Suggested materials for examination are glass, rubber, plastics and salt. Mixtures of materials can be found naturally such as granite. Special properties can be realized by combining various materials to obtain composite materials that have properties superior to the individual constituents.
	144.2 Homogeneous materials	1442.1 Amorphous 1442.2 Crystalline 1442.3 Polycrystalline	432.1	All homogeneous materials do not have the same basic structure.	Amorphous Crystalline Polycrystalline Homogeneous		
	144.3 Heterogeneous materials	1443.1 Natural 1443.2 Artificial 1443.3 Ordered		Heterogeneous material may occur naturally but they can be processed industrially or otherwise to produce a material having different properties.	Laminates Honeycomb Foamed plastics		
14.5 Selection of materials *Estimated periods:* *4T* *4SA*	145.1 Criteria for choice	1451.1 Suitability for specific usage 1451.2 Availability 1451.3 Durability 1451.4 Appearance 1451.5 Cost	4222.9	A large number of factors influence the final choice of material. Economics is not the least in importance.	Creep Fatigue Fire resistance Obsolescence Esthetic Functional	**DESIGN PROBLEMS (X)** Problems involving the selection of materials for specific applications.	The student should be encouraged to look into the economic facts of production. Examine the whole aspect of manufacturing a product for a specific market.
	145.2 Economics	1452.1 Raw materials 1452.2 Manufacturing 1452.3 Storage and marketing costs		Cost analysis Law of supply and demand	Market surveys Numerical control Inventory		

INDUSTRIAL PHYSICS G.S-27C DIVISION TWO: FLUIDS

UNIT: 2.1 Fundamentals of Hydraulics

		Element	Cross-reference	Fundamentals	Technical Terms	Student Activity	Discussion
21.1 Introduction to fluids *Estimated periods: 2T*	**211.1 Historical development of fluid mechanics**	2111.1 Branches of fluid mechanics 2111.2 Past and present applications 2111.3 Merits of fluid power systems		Energy transfer Rate of response	Fluids, hydraulics, pneumatics Fluids, liquids, sluice gate Air foil, compressibility		Discuss the use of control dams for irrigation of the Nile valley by ancient Egyptian civilizations. Describe the works of the Romans with respect to water supply and sewage disposal. Trace the use of rudimentary hydraulics through the industrial revolution to present day. Include the modern day fluid type computer application. Viscosity can be compared with elasticity in shear; in addition it includes rate of shear. Pupils may be required to convert from American to metric systems. They should be familiar with S.A.E. viscosity grading. Emphasize the aspects of safe handling of liquids. Fluids should be considered incompressible, for most practical applications. Emphasize that Pascal's Law applies to fluids at rest only.
21.2 Liquids *Estimated periods: 2T 2SA*	**212.1 Chemical properties**	2121.1 Chemical activity 2121.2 Corrosivity 2121.3 Oxidation 2121.4 Fire resistance	341.2 1414.1 1424.1	Activity series Oxidation	Chemical properties Corrosivity Oxidation Fire resistance Petroleum Physical properties Emulsion Viscosity Viscosity index Compressibility Pour point Foaming	**CORROSIVITY (E)** To examine the activity of materials placed in close contact under various conditions. **FIRE RESISTANT PROPERTIES (E)** To compare various liquids as to their ability to withstand high temperatures. **VISCOSITY (E)** To compare the inherent viscosities of oils at various temperatures.	
	212.2 Physical properties	2122.1 Viscosity 2122.2 Compressibility 2122.3 Tendency to foam	341.1 241.1	Internal friction Molecular cohesion Kinetic molecular theory			
21.3 Hydrostatics *Estimated periods: 3T 5SA*	**213.1 Pressure in a static fluid**	2131.1 Force and pressure 2131.2 Static head 2131.3 Pascal's Law	**11.1** 131.3 311.1 311.2 313.1 321.1	Static Uniform gradient P (g) = sW x H	Static Pressure Force Static head Pascal's Law	**PASCAL'S LAW (E)** To verify Pascal's Law. **STATIC HEAD (E)** To measure the static head produced by a liquid. **FORCE MULTIPLICATION (E)** To show the multiplication of force which occurs when a small cylinder is used to supply fluid to a larger cylinder. **HYDRAULIC JACK (E)** To study the operation of a hydraulic jack.	
	213.2 Force multiplication	2132.1 The force exerted on a piston 2132.2 Two pistons of different areas interconnected by means of a flow channel	321.1 2131.3	Action and reaction Force balance system Mechanical advantage F = rPA $D_2 = D_1\left(\frac{A_1}{A_2}\right)$ $P = \frac{F_1}{A_1} = \frac{F_2}{A_2}$	Force balance Mechanical advantage		
21.4 Fluid dynamics *Estimated periods: 13T 8SA*	**214.1 Continuity principle**	2141.1 Volume and flow velocity 2141.2 Units of flow and their interconversion	31.2 4122.4 241.2	Continuity $Q = A_1 V_1 = A_2 V_2$	Continuity principle Imperial gallons; U.S. gallons	**CONTINUITY PRINCIPLE (E)** To prove the continuity principle. **FRICTION HEAD (E)** To study the head loss in pipe flaw due to friction. **LIFT AND DRAG (E)** To study the lift and drag of an object in a wind tunnel and smoke chamber. **PELTON WHEEL (E)** To study force and power relationships for a simple pelton turbine.	Discuss the use of simple monographs. For incompressible flow this would be: $P_1 A_1 V_1 = P_2 A_2 V_2$ It is not necessary to include the concept of internal energy at this level. The analogy with Kirchhoff's Law is evident here. Simple equipment is available for meaningful experiments in aerodynamics. Hydro-electric power stations are excellent examples of fluid-dynamic applications, as are automobile automatic transmissions.
	214.2 Conservation of energy	2142.1 Work, energy, and power 2142.2 Conservation of energy and momentum in a fluid system 2142.3 Kinetic and potential energy factors in Bernoulli's Principle	314.2 124.1 124.3 412.3 **1242.2** **124.2** 312.2	Inertia E_{tot} = PE + KE + pressure energy $\frac{Z_1+V_1^2}{2g} + \frac{P_1}{d} = \frac{Z_2+V_2^2}{2g} + \frac{P_2}{d}$ $Ft = mv_1 - mv_2$ F = ma	Surge pressure etc. Work Power Energy Friction Heat Potential energy Kinetic energy Pressure energy Weight density (d)		
	214.3 Fluid flow	2143.1 Laminar flow 2143.2 Turbulent flow 2143.3 Heat generation because of flow under pressure	31.2 **1242.3** 2142.1 111.2 4144.2	Gradient Conservation of energy Energy conversion: Friction	Friction Gradient Pathline Streamline Laminar Turbulent Mechanical equivalent of heat		
	214.4 Forces on bodies immersed in moving fluids	2144.1 Lift 2144.2 Drag	312.2	Lift = C_L ½ PV^2 A Drag = C_d ½ PV^2 A	Lift: drag Coefficient of lift Stall Coefficient of drag		
	214.5 Fluid-dynamic applications	2145.1 The water turbine 2145.2 Hydraulic coupling 2145.3 Torque converter	312.2 22.4 25.3	Energy transfer and conversion	Turbine Hydraulic coupling Torque converter		

UNIT: 2.2 Hydraulic Components

		Element	Cross-reference	Fundamentals	Technical Terms	Student Activity	Discussion
22.1 Valve construction and operation *Estimated periods: 5T 8SA*	**221.1 Pressure control**	2211.1 Relief 2211.2 Reducing 2211.3 Sequencing 2211.4 Unloading	3.3 443.2 422.1 2312.4 2312.5 2542.4 2542.5	Control (C) Sequence	Cracking pressure Pressure override Full flow pressure Fail-safe Throttle action Spool, restriction	**VALVE CHARACTERISTIC STUDY (E)** To study and compare the operating characteristics of a simple relief valve. **FLOW CONTROL VALVES (E)** To study the operating characteristics of a flow control valve and make a graph of these characteristics. **DIRECTIONAL CONTROL VALVES (E)** To examine the construction and internal operation of several directional control valves. **ELECTROSOLENOID VALVES (E)** To show the operation of an electrosolenoid valve.	The study of valves at this point should be concerned with the construction and operation of the valve. Whenever possible, the student should plot and interpret graphs. The use of pilot-operated valves should be stressed from the standpoint of remote operation. The check valve is the fluid controlling counterpart of the electrical diode in that free flow is allowed in one direction and restricted flow in the other. Whenever possible, the interconvertibility of energy types and the conversion of potential energy into kinetic energy should be amply discussed.
	221.2 Volume control (flow limiting)	2212.1 Non-pressure compensated 2212.2 Pressure compensated	3311.1	Volume = area × velocity Compensation (C)	Pressure compensation		
	221.3 Directional control	2213.1 Check valve 2213.2 Two-way 2213.3 Three-way 2213.4 Four-way 2213.5 Multiple centre position	431.1 432.1 441.4	Unidirectional flow (C) Switching	Ball check valve Spool valve Poppet valve Closed centre Tandem centre		
	221.4 Pilot operation	2214.1 Pneumatically actuated 2214.2 Hydraulically actuated 2214.3 Electrosolenoid operated	2541.3 4133.4 3311.1 2521.2	Remote operation	Electrosolenoid Pilot valve Double pilot operated valve		
22.2 Actuators *Estimated periods: 3T 3SA*	**222.1 Classification of types**	2221.1 Single acting cylinders 2221.2 Double acting cylinders 2221.3 Rotary	25.3	Rectilinear motion Rotary motion F = A × P Power = k × pressure × flow rate Torque = F × moment arm	Rectilinear motion Rotary motion Single acting cylinder Double acting cylinder Ram Piston Cylinder Actuator Vanes — double and single	**THE DOUBLE ACTING CYLINDER (E)** To examine the double acting cylinder as to constructional details. **ACTUATORS (A)** To examine the adaptations made to basic cylinders to accommodate specific industrial needs.	Stress the need for chemical compatibility of materials used in any system. Discuss the development of specially adapted components to suit specific needs.
	222.2 Design features	2222.1 Pressure rating 2222.2 Chemical compatibility of parts 2222.3 Materials 2222.4 Mounting configuration 2222.5 Selection for specific function	**212.1** 14.5	Stress = $\frac{F}{A}$ Hoop stress Chemical activity	Safety factor Chemical compatibility Hoop stress Fixed-centerline mounts Fixed-non-centerline mounts Pivoted mounts Misalignment U-ring Flange U-cup O-ring		
22.3 Pumps *Estimated periods: 6T 4SA*	**223.1 Classification of types**	2231.1 Positive displacement 2231.2 Rotary 2231.3 Fixed displacement 2231.4 Reciprocating	251.1	Positive displacement Reciprocating Energy conversion	Vane Gear Piston Axial Radial Screw Lobe Diaphragm Centrifugal Propellers	**PUMP STUDY (A)** To examine two types of pumps on the basis of geometry of the pumping mechanism and principle of operation. **PUMP TEST (E)** To determine the total dynamic head, the hydraulic horsepower, and pump horsepower of a centrifugal pump. **PUMP CHARACTERISTICS (E)** To study the relationship between capacity, head, efficiency and horsepower in a positive displacement pump.	The total dynamic head against which the pump operates is the sum of the changes in elevation; i.e., static head, change in velocity head of the fluid from intake to discharge of the pumps, and of head lost due to friction. Study only a few pump types in theoretical detail and operating characteristics. Note the similarities between the hydraulic pump and motor.
	223.2 Performance characteristics	2232.1 Energy relationships 2232.2 Efficiency 2232.3 Specific application as a function of performance characteristics	2511.3 214.2 412.3 42.2	Conservation of energy Total dynamic head $= Z_2 - Z_1 + \left(\frac{V^2}{2g} - \frac{U^2}{2g}\right) + \frac{P_2 - P_1}{d} + H_L$ Ideal Hp = $\frac{E_2\,d\,Q}{33,000}$	Mixed flow Turbine Jet Total dynamic head Velocity head ($V^2/2g$) Static head (Z) Efficiency Work Horsepower Capacity		
22.4 Motors *Estimated periods: 3T 2SA*	**224.1 Classification of types**	2241.1 Gear 2241.2 Vane 2241.3 Axial piston 2241.4 Radial piston	253.2	Rotary motion Hp = R × rate of fluid flow × pressure change	Total dynamic head Velocity head Static head Efficiency Work Horsepower Capacity	**MOTOR STUDY (A)** To examine the gear motor on the basis of geometry of the mechanism and principle of operation. **PERFORMANCE CHARACTERISTICS (A)** To use monographs as the basis of discussion regarding the operating characteristics of hydraulic motors.	Discuss the significance of characteristic performance curves in the selection of a motor to perform a specific task.
	224.2 Performance characteristics	2242.1 Energy relationships 2242.2 Efficiency 2242.3 Specific application as a function of performance characteristics	422.2 2511.3 214.2 412.3 42.2	Conservation of energy Energy conversion	Performance characteristic Efficiency Cavitation		
22.5 Ancillary components *Estimated periods: 3T 4SA*	**225.1 Fluid conditioning, transport and systems sealing apparatus**	2251.1 Oil filters 2251.2 Fittings and seals 2251.3 Connecting tubing	441.3	Mechanical sorting Chemical compatibility	Fitting Seal Oil filter	**IDENTIFICATION STUDY OF PIPES, TUBES, HOSES, AND FITTINGS (A)** **SHOCK ABSORPTION STUDY (A)** To examine the use of shock absorbing applications.	The oil filter is actually a mechanical sorter. The student should understand use of fluids for shock absorbing purposes. Frequently the inertia of the load being moved is overcome by means of energy absorption at the end of the stroke. Failure to cushion in this may result in the destruction of the cylinders.
	225.2 Storage devices	2252.1 Reservoirs 2252.2 Accumulators 2252.3 Shock absorbing apparatus	**124.2** 421.3 421.2 442.3	Inertia Elasticity Potential energy Damping (C)	Reservoir Accumulator Shock absorber		

INDUSTRIAL PHYSICS G.S-27C DIVISION TWO: FLUIDS

UNIT: 2.3 Hydraulic Circuits

23.1 Analysis — *Estimated periods: 5T 19SA*

Sub-section	Element	Cross-reference	Fundamentals	Technical Terms
231.1 Elementary circuits	2311.1 Single cylinder direction control 2311.2 Single cylinder velocity control 2311.3 Single cylinder directionally controlled by an electrosolenoid valve 2311.4 The use of an accumulator	231.1 41.2 254.1 4133.4	Directional flow Pilot control Remote control Intensification	3-way valve 4-way valve Manually actuated, solenoid Pilot operated Feed side Return side Bypass Remote control Accumulator Source Sink Intensifier
231.2 Advanced circuits	2312.1 Cylinder travel limiting circuit 2312.2 Two-cylinder operation with independent control of both cylinders 2312.3 Series operation of two cylinders 2312.4 Semi-automatic sequence circuits 2312.5 Automatic sequence circuits using two cylinders	254.2 2542.4 2542.5	Response Sequence cycle Logic function Feedback (C) Binary action	Limited travel Response Independent control Semi-automatic operation Automatic operation Sequence Cycle Phase Logic function Feedback Binary action

Student Activity

DIRECTIONAL CONTROL (E)
To investigate the means by which the direction of travel of an actuator is obtained.

VELOCITY CONTROL (E)
To examine the three methods of controlling the velocity of an actuator.

ELECTROSOLENOID VALVES (E)
To use an electrosolenoid valve for directional control of an actuator.

THE ACCUMULATOR (E)
To show the use of an accumulator in a hydraulic circuit.

DISPLACEMENT CONTROL (E)
To study means of controlling the length of stroke of a cylinder.

INDEPENDENT CYLINDER CONTROL (E)
To study a two-cylinder circuit with independent control of each cylinder.

SERIES OPERATION OF TWO CYLINDERS (E)
To show the operation of two cylinders in series operation.

SEMI-AUTOMATIC CIRCUITS (E)
To investigate a semi-automatic circuit.

AUTOMATIC CIRCUITS (E)
To investigate a fully automatic sequence circuit.

Discussion

A progressive approach should be used in the development of increasingly complicated circuits. The student should realize that additional components are added in order to overcome some inherent disadvantage of a circuit. Means of velocity control should be thoroughly understood.

Stress the danger when releasing a charged accumulator.

The introduction of sequential circuits affords an excellent opportunity to deal with the subject of automation. The term automation need not be synonymous with complex apparatus. Complexity is often built into an automatic system by virtue of the sheer number of circuits. The student must have a clear understanding of the terms sequence, cycle, phase, and feedback.

UNIT: 2.4 Fundamentals of Pneumatics

24.1 Introduction to pneumatics — *Estimated periods: 4T 4SA*

Sub-section	Element	Cross-reference	Fundamentals	Technical Terms
241.1 Physical properties of gases	2411.1 Compressibility 2411.2 Pressure, temperature, volume relationships 2411.3 Viscosity	212.2 341.1	Kinetic molecular theory Boyle's Law Charles' Law $\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$	Boyle's Law Absolute pressure Absolute temperature Ideal gas Volume
241.2 Gas flow	2412.1 Steady flow through pipes 2412.2 Gas flow through a restriction	214.1 4122.4 31.2	Continuity Principle Bernoulli's Principle $P_1 A_1 V_1 = P_2 A_2 V_2$	Continuity Principle Bernoulli's Principle Venturi Pitot Tube
241.3 Characteristics of pneumatic systems	2413.1 Rate of response 2413.2 Merits	442.1 415.7 31.4 331.1 2312.5	Time constant Cohesion Adhesion Viscosity	Response rate Cohesion Adhesion

Student Activity

BOYLE'S LAW (E)
To demonstrate Boyle's Law.

CHARLES' LAW (E)
To demonstrate Charles' Law.

CHARACTERISTICS OF PENUMATIC-SYSTEMS (E)
To compare the rates of response of pneumatic and hydraulic systems.

Discussion

Be sure to discuss the effect of gas compressibility in the operation of pneumatic circuits. Rapid rate of response in pneumatic circuits is accounted for by the low viscosity of air.

The student should be truly familiar with the fact that heat is produced when a gas is compressed and the converse.

UNIT: 2.5 Pneumatic Components and Circuits

25.1 Air compressor and accessories — *Estimated periods: 3T 3SA*

Sub-section	Element	Cross-reference	Fundamentals	Technical Terms
251.1 Positive displacement type piston compressor	2511.1 Construction of single and double stage compressors 2511.2 Use of intercoolers 2511.3 Rating	22.3 223.2	Compression Laws of thermodynamics	Thermodynamics The laws of thermodynamics The kinetic molecular theory as applied to gases Aftercooler
251.2 Air storage distribution systems	2512.1 The unloading valve 2512.2 Air receiver 2512.3 Air pressure regulation, filtration and lubrication 2512.4 Typical installation	124.2 225.2 421.2 421.3 441.3	Pressure drop Mechanical sorting Potential energy	The unloading valve Filter Lubricator Regulator Unloading valve Dew point Humidity Hydrostatic testing Factor of safety

Student Activity

IDENTIFICATION STUDY OF THE SCHOOL AIR COMPRESSOR (A)
To become familiar with the type, name capacity, power and means of cooling for the school air compressor.

REGULATOR FILTER LUBRICATOR UNIT (E)
To examine the r.f.l. unit as to function and operation.

THE SCHOOL AIR SYSTEM (A)
To examine the school air distribution system in detail.

Discussion

A simplified calculation of the energy stored in a pressure vessel might be used to emphasize the necessity for care in constructing receivers. Mention existing laws governing design, construction, and inspection.

Mention the use of pressure switches to conserve power in simpler operations.

25.2 Valve construction and operation — *Estimated periods: 6T 8SA*

Sub-section	Element	Cross-reference	Fundamentals	Technical Terms
252.1 Directional control	2521.1 Comparison of hydraulic and pneumatic directional valves re: paths of flow 2521.2 Manual, pilot, solenoid and cam actuation of pneumatic valves 2521.3 Construction	221.3 431.1 432.1 432.2	Pilot operation Remote operation	Spool type Lands type Poppet type 2-way valve 3-way valve 4-way valve Flow pattern Detent Solenoid Pilot
252.2 Flow control	2522.1 Throttle and restriction types 2522.2 Flow control valve characteristics	221.2 3311.1	Throttling Volume = area × velocity Compensation (C)	Throttling Pressure compensated valve
252.3 Sequence valves	2523.1 Principle of operation 2523.2 Function	2312.4 2542.4	Sequence (C)	Sequence valve

Student Activity

IDENTIFICATION STUDY OF DIRECTIONAL VALVES (E)
To examine the internal construction of a number of pneumatic valves.

FLOW CONTROL VALVES (E)
To study the flow characteristics of a pressure compensated flow control valve.

Discussion

If pneumatics is studied first, more time should be spent on this section. If hydraulic valves have already been investigated, the student will require less time to become familiar with pneumatic valves. Be sure to use standard symbols. A demonstration of a solenoid valve operated by a photoelectric relay switch is interesting to the student.

25.3 Pneumatic actuators — *Estimated periods: 2T 2SA*

Sub-section	Element	Cross-reference	Fundamentals	Technical Terms
253.1 Linear	2531.1 The single acting cylinder 2531.2 The double acting cylinder	2221.1 2221.2	Linearity (C) Rectilinear motion	Rectilinear motion
253.2 Rotary	2532.1 The rotary air motor	2221.3 22.4	Rotary motion	Rotary motion

Student Activity

THE DOUBLE ACTING CYLINDER (E)
To measure the thrust produced by a cylinder at various air pressures.

25.4 Circuits — *Estimated periods: 5T 19SA*

Sub-section	Element	Cross-reference	Fundamentals	Technical Terms
254.1 Basic circuits	2541.1 Single cylinder direction control 2541.2 Cylinder rate of travel control 2541.3 Pilot operated cylinder control	231.1 41.2 254.1	Directional flow Pilot control Remote control Intensification	3-way valve Flow control valve Pilot operated valve Remote control Feed side Return side Bypass Pressure drop
254.2 Advanced circuits	2542.1 Cylinder travel limiting circuits 2542.2 Rapid cycling circuits 2542.3 Series operation of two cylinders 2542.4 Semi-automatic sequence circuits 2542.5 Automatic sequence circuits	231.2 4.4 2312.4 2542.4 252.3	Response time Automatic Sequence (C) Logic function Binary action	Limited travel Response Semi-automatic Automatic Feedback Binary action Sequence Cycle Phase

Student Activity

DIRECTION CONTROL (E)
To show the use of 3-way and 4-way valves as direction determining devices.

SPEED CONTROL (E)
To demonstrate the 3 methods of pneumatic circuit actuator control.

PILOT OPERATED VALVES (E)
To show the use of pilot operated valves in a pneumatic circuit.

CYLINDER TRAVEL LIMITATION (E)
To investigate the cam operated valve as a means of displacement limitation.

PNEUMATIC OSCILLATING CIRCUIT (E)
To investigate the operation of a circuit to produce rapid cylinder oscillation.

SERIES CIRCUITS (E)
To demonstrate the operation of two cylinders in series operation.

SEMI-AUTOMATIC OPERATION (E)
To demonstrate semi-automatic operation.

AUTOMATIC SEQUENCE CIRCUITS (E)
To demonstrate an automatic sequence circuit.

Discussion

Emphasize the "development by function" of increasing complex circuits.

The double pilot operated 4-way valve, is an excellent example of a flip-flop logic function.

The operation of advanced circuits should be approached from the standpoint of logic function. With automatic circuits, the student should be aware of the source of the feedback signal to begin a new cycle.

The rapid rate of response of pneumatic circuits is easily demonstrated by means of a short stroke oscillating circuit.

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DIVISION THREE: INSTRUMENTATION

UNIT: 3.1 Measurement and Indication

Topic	Subtopic	Element	Cross-reference	Fundamentals	Technical Terms	Student Activity	Discussion
31.1 Pressure *Estimated periods: 9T 11SA*	311.1 The physical nature of pressure	3111.1 The molecular structure of fluids 3111.2 Pressure proportional to height of fluid 3111.3 Pressure proportional to weight density of fluid 3111.4 Pressure × volume is constant 3111.5 Types of pressure: absolute, gauge	131.3 213.1 2411.2	Pressure concept in kinetic molecular theory Boyle's Law $P = kdH$ $\frac{PV}{T} = k$	Pressure Kinetic energy of molecules Absolute pressure, gauge pressure Weight density (d)	**BALLOON PRESSURE (E)** To investigate pressure and force with an inflated balloon. **BAROMETRIC PRESSURE (E)** To record barometric pressure for several days, using: • An aneroid barometer • A mercury barometer **PRESSURE MEASUREMENT (E)** To measure a sequence of fixed pressure sources with: • Manometer filled with (1) mercury (2) water • Inclined manometer filled with mercury • A bourdon type gauge • A bellows type gauge	The student must understand that the energy possessed by a fluid is due to the movement of its molecules. Stress that atmospheric pressure is caused by the "weight" of the atmosphere. The inherent accuracy of the various instruments should be stressed. Distinguish between primary and secondary standards.
	311.2 Primary measuring methods	3112.1 The well-type manometer as a device to convert pressure to a linear scale reading 3112.2 Effect of liquid density on range and sensitivity 3112.3 The inclined manometer as a means of extending sensitivity and scale expansion 3112.4 The bourdon tube gauge: construction and principles of operation 3112.5 The bellows: construction, area effect and range selection through internal pressure	213.1 423.1 444.2 1311.3	Force balance systems Sensitivity (C) Density Deformation of material under stress Transformation of a static pressure to a linear motion Hooke's Law	Manometer Linear scale Range, span Instrument sensitivity Repeatability Liquid density Deformation, stress Static pressure Hysteresis Elastic		
31.2 Flow *Estimated periods: 12T 20SA*	312.1 Flow characteristics	3121.1 Ideal flow: total energy remains constant 3121.2 Real flow 3121.3 Types of flow: laminar, turbulent	214.3 214.2 241.2 4122.4	Bernoulli's Theorem $\frac{P}{d} + \frac{v^2}{2g} = \text{constant}$ $\frac{P_1}{d} + \frac{v_1^2}{2g} = \frac{P_2}{d} + \frac{v_2^2}{2g}$ Conservation of energy $Q_{rate} = KA_1v_1 = KA_2v_2$ $v = \sqrt{2gh}$	Pressure head (P) Weight density (d) Inviscid Fluid friction Boundary layer Laminar: turbulent flow Viscosity	**VELOCITY OF A JET (E)** To calculate average velocity of a liquid from a jet at the base of a tank with a constant head "h". Compare the measured value with $\sqrt{2gh}$. Determine the loss in head due to fluid friction. **PRESSURE DROP ACROSS ORIFICE PLATE (E)** To measure the pressure drop across an orifice plate for various known flows of water. (Obtain flow values from rotameter.) Plot graph of flow versus pressure loss. **TOTAL FLOW (INTEGRATION) (E)** To measure total flow, using a "Buffalo" type water meter. Record the time required, and thus calculate the rate of flow. **THE ODOMETER (A)** Examine the odometer from an automobile and compare it with the Buffalo meter as to working principle.	The average velocity of the jet can be calculated by the trajectory distance. The vertical drop in air serves as a clock: $t = \sqrt{\frac{2h}{g}}$ The horizontal distance $x = v\,t$. Various industrial applications where flow is measured, should be discussed. Rotameters may be calibrated in U.S. or Imperial gallons. The concepts of rate of flow and total flow can be used to demonstrate the concept of mathematical integration. The students should recognize the bob and tape method as being messy and unscientific. Mention difficulties which arise if liquid is corrosive. Columns used for liquid measurement may be different from liquid being measured. The many physical principles used in sensing of level should be emphasized.
	312.2 Rate-of-flow meters	3122.1 Differential pressure meters: pressure change across a restriction 3122.2 Constant-force variable-area meter	423.1 214.4	$v = \sqrt{2gh} = \sqrt{2g\frac{P_1 - P_2}{d}}$ $Q_{rate} = kA\sqrt{2gh}$ Static equilibrium	Orifice plate Flow nozzle Venturi tube Viscosity		
	312.3 Total flow meters	3123.1 Positive displacement meters: capture, count, and release a fixed quantity of material		Integration (C) $Q_{total} = knV$	Rotameter, purge meter Mechanical integration Mechanical counting, total flow Positive displacement meter Number of revolutions (n)		
31.3 Level *Estimated periods: 12T 15SA*	313.1 Direct liquid level measurement	3131.1 Bob and tape 3131.2 Sight glass: factors affecting accuracy of reading 3131.3 Inert float system: counterweight function, mechanical advantage 3131.4 Displacer type torque function	 113.1 442.1	Reference datum Surface tension; adhesion, cohesion Pascal's Law Force balance systems Archimedes Principle Amplification (C) Linear to angular motion	Linear measurement British, metric units of length Capillary, cohesion, adhesion Convex, concave meniscus Liquid Buoyancy Displacement amplification Moment, torque	**SIGHT GLASS (E)** • To observe the convex and concave meniscus, using sight glasses which are, (1) open-ended, (2) in closed containers. • Compare this method with bob and tape. **INERT FLOAT SYSTEM (P)** To construct and use an inert float system. **AIR TRAP (P)** Construct an air trap using bubbler system. To check the fixed points of several thermometers.	The factors that can be discussed with respect to the bubbler system are: • Uniformity of pressure in the air system due to small weight density (no head effect) and low flow (no pressure drop). • Effect of surface tension (shape of bubbler outlet).
	313.2 Indirect level measurements	3132.1 Air trap: pressure within a liquid varies as the depth and density 3132.2 Bubbler system, factors affecting air supply	1415.1 1426.1 2131.3	Force balance system Elasticity Solubility (C) $P = kHd$ Pascal's Law Hydrostatic balance	Hydrostatic pressure Solubility Rotameter		
31.4 Temperature *Estimated periods: 12T 15SA*	314.1 Changes in the physical properties of materials	3141.1 Volume and length change with temperature 3141.2 Fixed points as reference temperatures define scales 3141.3 Electrical resistance changes 3141.4 Time constant	142.3 3231.4 4121.3 4147.4	$L = L_o(1 + \alpha t)$ Rate of response Concept of absolute zero temperature Resistance heating $R_t = R_o(1 + \alpha t)$ $\Delta R = R_o \alpha \Delta T$	Linear expansivity Bimetallic strip Elongation Centigrade Celsius Kelvin Rankine Ice point Steam point Time constant Coefficient of resistivity Thermistor Wheatstone bridge	**THERMOMETER SCALES (E)** To check the fixed points of several thermometers. **TIME CONSTANT (E)** To measure the time constant of several thermometers. **RESISTANCE THERMOMETER (E)** To graph resistance vs. temperature for chromel wire and thermistor. **OPTICAL PYROMETER (E)** Use an optical pyrometer to measure the temperature of various high temperature sources such as bulb filaments, bunsen burner, flame, etc.	Temperature measurement is the object of this section and incurs all the principles entailed, which are: • Rate of rise of temperature. • Methods of heat transfer. • Time constant and lag. • Heat capacity. • Percent emissivity. • Analogy — between r.c. circuits and temperature transfer.
	314.2 Radiant energy	3142.1 The optical pyrometer: the colour of a hot object indicates its temperature 3142.2 Visible radiant energy from a bulb filament can be matched to colour of a hot body 3142.3 Percent emissivity and black body concept	1413.2 1423.2 43.3	Heat transfer Stefan Boltzmann Law $E = KT^4$ Spectral response: Human eye as a frequency detector	Radiant energy Angstrom Total absorption Spectrum Optical pyrometer Infra-red radiation Black body Emissivity		

UNIT: 3.2 Transmitting and Receiving Devices

Topic	Subtopic	Element	Cross-reference	Fundamentals	Technical Terms	Student Activity	Discussion
32.1 Pressure and level transmitters *Estimated periods: 3T 5SA*	321.1 Theory of operation	3211.1 Nozzle and flapper principles 3211.2 Elastic deformation of sensing element	442.1 131.1	$S = \frac{F}{A}$ Force amplification Pascal's Law Hooke's Law	Elastic deformation Range, span Hysteresis (mechanical) Linear response Recovery rate Proportionality Diagnosis	**PRESSURE TRANSMITTER (A) (E)** • To examine a commercial pressure transmitter with regard to construction and operation. • To plot a graph of pressure input vs. pressure output. **CALIBRATION OF TRANSMITTER (E)** To calibrate the above transmitter as per manufacturer's instructions.	Section 32.1 presents an occasion to mechanically produce situations of information transfer, and factors which affect the characteristics of same which are: interpretation of departures from linearity of input-output curves (s-curves, multiplication errors, or zero shift) in terms of primary element, angularity, hysteresis, linkage lengths, ouput nozzle restrictions. The differential pressure transmitter with a bellows type element is recommended. The inverted bell, U-tube, manometer and ring types can also be discussed.
	321.2 Design considerations	3212.1 Linear response of system 3212.2 Proportional transmitter output	442.1 444.2	Linearity (C) Proportionality (C)			
	321.3 Calibration	3213.1 Methods and procedures: correct diagnostic approach 3213.2 Adjustment of range, span, sensitivity	423.1 322.2 444.2	Diagnostic approach			
32.2 Flow transmitters *Estimated periods: 3T 4SA*	322.1 Differential pressure transmitters	3221.1 Pressure transmitters adapted for a differential measurement 3221.2 Moment arm and fulcrum considerations 3221.3 Application: transmitting flow information	3212.2 113.1	Differential measurement Square root function $S = \frac{F}{A}$ Hooke's Law	Static force Equilibrium Differential Classes of lever Moment Square root function	**DIFFERENTIAL PRESSURE TRANSMITTER (A) (E)** • To examine a commercial differential pressure transmitter with regard to construction and operation. • To plot a graph of differential pressure input vs. pressure output. **CALIBRATION OF DIFFERENTIAL TRANSMITTER (E)** To calibrate a differential transmitter as per manufacturer's instructions.	
	322.2 Calibration	3222.1 Methods and procedures: correct diagnostic approach 3222.2 Adjustment of range, span, sensitivity	423.1 444.2	Lever principle			
32.3 Receiving devices *Estimated periods: 2T 3SA*	323.1 Universal recorders	3231.1 Limited range type pressure sensitive elements 3231.2 Chart drive as a time base function 3231.3 Chart scale considerations and scribing techniques 3231.4 Calibration of span, linearity and reference datum	423.1 311.2 444.2 3312.3 3141.2 42.3 442.2 444.2	Time base (C) Mechanical memory (C) Monitoring Proportionality (C) Accepted calibration practice Linearity (C) Reference datum	Time base Dynamic error Chart drive Proportionality Monitoring (continuous)	**UNIVERSAL RECORDERS (A) (E)** • To examine universal recorders as to construction and operation. • To compare various static pressures, (1) directly from source (2) transmitted to universal recorder. • To calibrate as per manufacturer's instructions.	Discuss the advantages of the recorder over a plain gauge. Stress the frequent use in process instrumentation. X-Y recorders should not be neglected from the discussion; students should realize the time base can be produced by means other than chart movement.

UNIT: 3.3 Control

Topic	Subtopic	Element	Cross-reference	Fundamentals	Technical Terms	Student Activity	Discussion
33.1 Control mechanics *Estimated periods: 10T 10SA*	331.1 Control system analysis	3311.1 Components: primary sensing elements; transmitter; recorder or indicator; controller; final element 3311.2 Block diagram	442.3 122.3 414.7 2413.1	Feedback (C) Action and reaction Time constants	Dead time; lag time Feedback; closed loop system Measured variable Controlled variable Primary sensing element Controller	**CLOSED LOOP SYSTEMS (A)** To examine the operation of domestic closed loop systems such as: • Toilet • Hot water heater **COMMERCIAL CONTROLLER (A)** To examine carefully a high-quality commercial controller. **CONTROLLER PROJECT (P)** To construct a control system which will maintain a constant flow under a variety of load conditions (proportional plus reset plus rate)	Applications which are present in the environment of the student should be used whenever possible; for example, a hot air furnace system. The student might be given, as a small research project, the assignment to compare the number and kinds of automatic on-off domestic applications in use today with those in common use 15 years ago.
	331.2 Modes of control (O)	3312.1 On-off applications 3312.2 On-off limitations 3312.3 Proportional applications 3312.4 Proportional limitations 3312.5 Proportional plus reset 3312.6 Proportional plus reset plus rate-action	432.2 1311.1 323.1	Binary operation Proportionality (C) Feedback	Deviation Off-set Sinusoidal cycling Binary: (flip-flop) Set point Transfer lag Proportional band and control Reset Rate-action Load change		

UNIT: 3.4 Analysis

Topic	Subtopic	Element	Cross-reference	Fundamentals	Technical Terms	Student Activity	Discussion
34.1 Fluid properties *Estimated periods: 5T 5SA*	341.1 Viscosity	3411.1 Units of viscosity: saybolt, poises and centipoises 3411.2 The stormer viscosimeter: rate of paddle rotation as a function of viscosity 3411.3 Bell method: time of fall 3411.4 Effect of temperature on viscosity	2122.1 122.3	Molecular cohesion Fluid friction Universal gravitation Force balance system	Cohesion Adhesion Torque Viscosity Saybolt unit Poise	**VISCOSITY (E)** To develop data for a plot of viscosity vs. temperature for 2 motor oils (#10, 30), using either or both viscosimeters. **Ph STUDY (E)** To use a commercial Ph meter in the accurate measurement of Ph for various solutions. **THERMAL CONDUCTIVITY CELL (E)** To analyse a gas sample by thermal conductivity method.	The industrial measurement of Ph is of importance in such applications as sewage treatment, paper manufacture and chemical engineering. The cooling effect of the gas must be caused by differences in the composition of the gases, not by variations in the flow rate.
	341.2 Ph	3412.1 The glass electrode method	411.4	Acidic vs. basic solutions Chemical activity	Ph Thermal compensation Permeable membrane Reference electrode Dissociation		
	341.3 Gas thermal conductivity	3413.1 Resistance of element in thermal conductivity cell as a function of surrounding gas 3413.2 Column activity (in gas chromatography)	1422.3 423.2	Graham's Law of diffusion Thermal conductivity of gases Deviation from standard	Thermal conductivity cell Measuring bridge		

INDUSTRIAL PHYSICS G.S-27C

DIVISION FOUR: ELECTRICITY

UNIT: 4.1 Fundamentals of Electricity and Magnetism

41.1 Electron phenomena

Estimated periods: 3T 3SA

	Element	Cross-reference	Fundamentals	Technical Terms
411.1 Electron Theory	4111.1 Structure of matter 4111.2 Atomic structure 4111.3 Periodic table	**111.1** 4121.1 43.1	The Bohr atom Dynamic stability (C) Periodicity (C)	Atom Molecule Element, compound Electron, proton, neutron, nucleus Ion, valence electron Periodic table
411.2 Electrical charges	4112.1 Nature 4112.2 Units 4112.3 Laws	4213.1 **1111.2** 431.1 431.2 433.1 444.2	Law of Electrical Charges Coulomb's Law: $F = \frac{k q_1 q_2}{d^2}$ Newton's Third Law	Electrical charges: positive and negative Coulomb Inverse Square Law
411.3 Electrostatic fields	4113.1 Properties of electrostatic lines of force 4113.2 Simple electrostatic fields 4113.3 Electric field gradients	**1111.2** 4213.1 444.2	Fields of force	Electrostatic lines and fields Electric gradients Induced charges
411.4 Electrical potential	4114.1 Energy of a flowing charge 4114.2 Units of potential difference 4114.3 Methods of producing	4122.2 422.3 433.2	Potential energy Electromotive series: chemical effect Principle of electromagnetic induction Piezoelectric effect Photoelectric effect Seebeck effect	Potential difference: the volt EMF Electrical pressure Electromotive series Piezoelectric effects Photoelectric effects Electrochemical effects Thermocouple

Student Activity

ATOMIC STRUCTURE OF DIFFERENT ELEMENTS (X)
Investigate and make schematic diagrams of selected elements from periodic table.

COULOMB'S LAW (E)
To prove that the force between charged bodies is inversely proportional to the square of the distance between them.

Discussion

Reference should be made to the fact that many other particles are present in the nucleus, such as positrons and mesons.

Remind the students of the similarity between the Universal Law of Gravitation and Coulomb's Law.

Demonstrations of simple fields of force are possible with appropriate equipment.

The student should gain an accurate conception of potential difference: strictly speaking, it is not a "force" or a "pressure". Refer to P.S.S.C. Physics on this.

The various methods of producing an EMF should be reviewed briefly.

41.2 D.C. circuits

Estimated periods: 3T 3SA

	Element	Cross-reference	Fundamentals	Technical Terms
412.1 Electrical conductors and insulators	4121.1 Electrical properties of materials: classification 4121.2 Physical factors relating to resistance 4121.3 Temperature effects	142.2 **411.1** 433.3 3141.3	Conductivity (C) Resistivity: $R = \frac{KL}{A}$ $R_T = R_{20}(1 + \alpha T)$	Conductor, insulator, semiconductor Specific resistance (K) Circular mil area (A) Dielectric, dielectric strength Temperature coefficient (α) Standard temperature (20°C) Thermistor
412.2 Circuit analysis	4122.1 Kinds of electrical circuits 4122.2 Ohm's Law 4122.3 Parallel Resistance Law 4122.4 Kirchhoff's Laws	411.4 142.2 4133.1 214.1 241.2	Ohm's Law: $E = IR$ $R = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \cdots \frac{1}{R_n}}$ Kirchhoff's Voltage Law: $\Sigma E = 0$ Kirchhoff's Current Law: $\Sigma I = 0$	Series, parallel circuits Open, closed and short circuits Sigma (Σ)
412.3 Power and energy	4123.1 Definitions of energy and power 4123.2 Comparison of electrical with other units 4123.3 Efficiency	124.1 124.2 2142.1 414.8 223.2 4221.5 4222.4 4222.7	$P = EI$ Conservation of energy (C) Equivalence: 1 H.P. $\equiv$ 746 watts Efficiency $(\eta) = \frac{\text{output power}}{\text{input power}}$	Watt (P) Efficiency (η)

Student Activity

RESISTANCE-TEMPERATURE RELATIONSHIP (E)
To investigate the magnitude of resistance changes with temperature of some electrical conductor materials.

KIRCHHOFF'S LAWS (E)
To confirm Kirchhoff's Laws by experiment.

Discussion

The effect of the atomic structure of different materials on conductivity should be discussed.

In the resistance-temperature experiment, a thermistor might be used in addition to other materials.

As in much of Sections 41.1, 41.2 and 41.3, it is assumed that the students have studied the subject matter in earlier grades.

Efficiency and equivalence of units can best be learned by an experiment with an electrical motor — see Section 42.2.

The moving electron is the ultimate source of any magnetic field. Unless the effect of the moving electron is counterbalanced, the magnetic field will not be cancelled and will manifest itself.

Magnetic field strength can be measured with a fluxmeter as a demonstration.

41.3 Magnetism

Estimated periods: 4T 2SA

	Element	Cross-reference	Fundamentals	Technical Terms
413.1 Theory of magnetism	4131.1 The moving electron as a source of magnetism 4131.2 Atomic arrangement of domains 4131.3 Magnetic poles 4131.4 Properties of magnetic lines 4131.5 Simple magnetic fields	**4111.2** **1111.1** 42.2 421.2 413.3	Magnetization Law of Magnetic Poles Lines of force (C) Energy storage	Domains, magnetic poles Magnetic lines and fields Natural, permanent and electromagnets Induced magnetism
413.2 Magnetic properties of materials	4132.1 Magnetic and non-magnetic 4132.2 Permeability 4132.3 Saturation 4132.4 Hysteresis	1422.4 4212.1 4221.5	Permeability (C) Saturation (C) Hysteresis	Permeability (μ) Saturation Hysteresis
413.3 Magnetic circuits	4133.1 Circuit law 4133.2 B-H curve 4133.3 Commercial materials 4133.4 Industrial applications: solenoids, relays, inductors, transformers, motors, saturable reactors	**4122.2** 142.2 **4132.2** 421.2 422.1 422.2	Flux $\propto \frac{\text{M.M.F.}}{\text{Reluctance}}$ Force-flux relationship Permeability: $\mu = B/H$	Flux, magnetomotive force, reluctance Flux density (B) Magnetizing force (H) Hysteresis loop Solenoid Relay Saturable reactor

Student Activity

PERMEABILITY (E)
To measure the **relative** permeability of various materials, using the fluxmeter.

MAGNETIC CIRCUIT CALCULATIONS (X)
Some simple problems using the B/H curves of commercial materials.

Discussion

Experiments to determine the relative hysteresis losses and saturation effects are also possible if suitable equipment is available. The importance of student participation cannot be over-emphasized.

The Magnetic Circuit Law is still another example of a "force-flux" relationship.

41.4 Alternating current circuits

Estimated periods: 12T 12SA

	Element	Cross-reference	Fundamentals	Technical Terms
414.1 Scalar and vector quantities	4141.1 Scalars: definition and examples 4141.2 Vectors: definition and examples 4141.3 Vectorial representation of electrical quantities 4141.4 Addition of vectors	1121.1 1121.2 112.2	Scalar quantities Vector quantities Vectorial representation	Scalar Vector Vector addition Alternating current
414.2 Sinusoidal waveform	4142.1 Sine wave generation 4142.2 Terminology: specific values 4142.3 Addition of waves of same frequency	4223.2 444.3 442.4	Sinusoidal waveform: $e = E_m \sin \theta$ Bidirectional (C) Periodicity (C)	Sinusoidal, sine waves Peak, RMS, average value Frequency, period, cycle, hertz Phase, in-phase, out-of-phase Audio frequencies, radio frequencies
414.3 Non-sinusoidal waveforms	4143.1 Addition of sine waves of different frequencies 4143.2 Square waves 4143.3 Sawtooth waves 4143.4 Pulses	444.3 442.4 444.2	Waveform composition Aperiodic (C)	Square waveforms Sawtooth waveforms Pulse waveforms Rise time
414.4 Purely resistive	4144.1 Phase relationships 4144.2 Power dissipation	**421.1**	Energy conversion	Phase relationship, phase angle Power dissipation
414.5 Purely inductive	4145.1 Phase relationships 4145.2 Inductive reactance 4145.3 Power dissipation	**421.2**	Lenz's Law Reactance: $X_L = 2\pi fL$ $X_L = \frac{E_L}{I_L}$	Inductive reactance (X_L) Lagging current
414.6 Purely capacitive	4146.1 Phase relationships 4146.2 Capacitive reactance 4146.3 Power dissipation	**421.3**	Reactance: $X_C = \frac{1}{2\pi fC}$: $X_C = \frac{E_C}{I_C}$	Capacitive reactance (X_C) Leading current
414.7 L-C-R circuits	4147.1 Impedance 4147.2 Vector diagram solutions 4147.3 Mathematical solutions 4147.4 Time constants: C-R and L-R circuits	4422.2 444.1 **1122.2** **1122.3** 4421.5 3141.4	Impedance: $E = IZ$ Impedance: $Z = \sqrt{R^2 + X^2}$ Vector representation Time constants: CR and L/R Expotential curves	Impedance Time constant Universal curves
414.8 Power	4148.1 Real power and apparent 4148.2 Power factor	**124.1** **124.2** **412.3**	Power factor: $\cos \theta$ $P.F. = \frac{P}{EI}$	Real power (P) Apparent power (EI) Power factor Cosine
414.9 Resonance	4149.1 Conditions at resonance 4149.2 Resonance in series circuits 4149.3 Resonance in parallel circuits	433.1 442.4 **414.7** 4421.5	Resonance (C) Selectivity (C) Figure of merit: $Q = \frac{X_L}{R}$	Resonance, selectivity Skin effect Figure of merit (Q) Bandwidth, bandpass, filter

Student Activity

VECTORS (X)
Problems which involve addition of vector quantities, some of them electrical.

ALTERNATING CURRENT WAVEFORMS (E)
- To observe sinusoidal waveforms on an oscilloscope.
- To observe square and sawtooth waveforms.

PHASE RELATIONSHIPS (E)
- To examine, with an oscilloscope, the phase relationships in L, C and R circuits.
- To make vector diagrams which indicate the approximate phase angle in each case, and the magnitude of applied voltage and current.

IMPEDANCE (E)
- To measure voltages in a series L-C-R circuit.
- Calculate the current, phase angles and impedance.
- To draw a vector diagram which depicts circuit conditions.
- To calculate the power losses.

TIME CONSTANTS (E)
- To measure and plot the time constant of several C-R combinations.

RESONANCE (E)
- To plot the resonance curve of an L-C circuit.

Discussion

The student should realize that circuits radiate energy (inefficiently) when carrying current at sixty hertz.

The RMS value of the square wave can be compared to the effective value of sinusoidal current by demonstrating the heating effect of each, or by using an amplifier and speaker system to compare loudness produced by waves of equal amplitude.

L-C-R circuits in combination can only be comprehended by the student if he has obtained a clear understanding of the "pure" circuits. Thus experiments and problems should be assigned prior to the analysis of an impedance condition.

If time permits, a similar experiment may be done with a parallel circuit. However, one should be certain that the series circuit is understood before attempting the parallel case.

Proficiency with the oscilloscope is assumed for most of these experiments.

The concept of time constant is not peculiar to electrical circuits but has many analogs, as in the measurement of temperature. The student should recognize the nature of the expotential curve as applied to time constants.

Resonance is, of course, a common phenomenon: it occurs in mechanical and optical systems.

The desirable and undesirable effects of resonance might be discussed: in power lines, filters and tuned R.F. circuits.

The resonance curve experiment may be done conveniently at audio frequencies, using a high Q choke and audio oscillator.

INDUSTRIAL PHYSICS G.S-27C DIVISION FOUR: ELECTRICITY

UNIT: 4.2 Electrical Devices

Component	Sub-topic	Element	Cross-reference	Fundamentals	Technical Terms	Student Activity	Discussion
42.1 Basic components *Estimated periods: 6T 8SA*	421.1 Resistors	4211.1 Fixed types 4211.2 Variable types	414.4 412.1	$R = \frac{KL}{A}$ $P = EI$ Resistance heating Proportionality (C)	Composition resistors Wirewound resistors Precision resistors Potentiometer, rheostat Carbon element, taper Strain gauges	**RESISTOR IDENTIFICATION (A)** To identify resistors by: • Type • Colour code • Power rating **INDUCTANCE MEASUREMENT (E)** To measure the inductance of several inductors, using a bridge or a Q-meter. **TYPES OF CAPACITORS (A)** To examine and compare commercial types of capacitors. **SERIES AND PARALLEL CAPACITANCE (E)** To measure the capacitance of known capacitors in series and in parallel.	Several resistor types may also be discussed, particularly non-inductive types. A resistor in the form of a moebius strip has interesting properties. If strain gauges are used in the I.P. laboratory, these should be discussed. The students should be able, upon examination of distinctly different types of inductors, to account for the differences in inductance. Simple capacitors can be made by the students, using aluminum foil and plastic dielectric. The shock hazards which exist with undischarged capacitors should be stressed.
	421.2 Inductors	4212.1 Iron-core types 4212.2 D.C. build-up in pure L circuit 4212.3 Energy of magnetic field 4212.4 Air-core types	413.3 414.5 4213.1 225.2 251.2	Inductance Principle of electromagnetic induction Faraday's Law: $E_{AV} = \frac{\Delta\phi}{\Delta t}$ Lenz's Law: $E_{AV} = -L\frac{\Delta I}{\Delta t}$ Energy storage	Self-inductance, inductor choke Henry Ferrite Figure of merit (Q)		
	421.3 Capacitors	4213.1 Elementary capacitor: energy stored in electrostatic form 4213.2 D.C. charge and discharge curves 4213.3 Factors affecting capacitance 4213.4 Commercial types 4213.5 Series and parallel connections	411.2 411.3 4212.3 4147.4 225.2 251.2 414.6	Energy storage $Q = CE$ $C \propto \frac{KA}{d}$ Expotential curves	Coulomb (Q) Farad (C) Dielectric constant (K) Dielectric strength Expotential curves		
42.2 A.C. machines *Estimated periods: 9T 13SA*	422.1 Transformer	4221.1 Transfer of energy by changing magnetic field 4221.2 Construction and function of each part 4221.3 Turn and voltage ratios 4221.4 Operating characteristics 4221.5 Losses and efficiency 4221.6 Polyphase connections	413.3 4222.4 4222.7 4223.5 4123.3 4222.5 4223.4	Electromagnetic induction Faraday's Law: $E_{av} = \frac{\Delta\phi}{\Delta t}$ Energy transfer: electrical and thermal $\frac{T_p}{T_s} = \frac{E_p}{E_s}$, $\frac{I_p}{I_s} = \frac{T_s}{T_p}$ $E = 4.44fNB_mA_c$ Regulation (C) Efficiency (η) $= \frac{P_{out}}{P_{in}}$	Transformer, mutual induction Primary, secondary winding Core, shell construction Step-down, step-up Turns-per-volt Flux density Voltage regulation Eddy currents, hysteresis Convection, conduction, radiation K.V.A. Polarity Wye, delta	**TRANSFORMER ACTION (E)** To confirm the relationships between turns ratios and voltage and current. **TRANSFORMER EFFICIENCY (E)** To measure the efficiency of an iron-core transformer under different loading conditions. **TRANSFORMER CONNECTIONS (E)** • To determine transformer polarity. • To connect single-phase transformers in three-phase configurations. **D.C. MOTOR (E)** To measure and graph the operating characteristics of a D.C. shunt motor. **SQUIRREL CAGE INDUCTION MOTOR (E)** • To determine the slip at several loads. • To measure the power factor and efficiency at several loads. **SINGLE-PHASE MOTORS (E)** To study the construction and operation of split-phase and capacitor-start induction motors. **THE ALTERNATOR (E)** To establish experimentally the relationships between frequency, terminal voltage, rate of rotation, and excitation.	The general transformer equation should be derived and fully discussed. It provides an excellent opportunity for the students to interpret a mathematical expression in terms of physical particulars. For these experiments, small transformers of a hundred or more volt-amperes are quite suitable. There is insufficient time to deal with motors fully. However, there are several important principles and concepts which may be taught without a detailed study of each motor type. The induction motor is equivalent to a transformer in which a low-resistance secondary is made capable of rotating with respect to the primary. A.C. motor operation is summarized in the graphs which depict speed regulation, efficiency, slip, horsepower, torque and power factor. The student should be able to interpret these graphs. The breadth of application of Faraday's Law is demonstrated again in the alternator. The output waveform from an elementary alternator will not be sinusoidal. This may be used to lead the students to appreciate the geometry of the machine. The teaching of this whole section will be expedited if the recurring patterns are pointed out and stressed.
	422.2 Motors	4222.1 Types 4222.2 Construction of D.C. motor 4222.3 D.C. motor principle 4222.4 Operating characteristics of shunt, series and compound types 4222.5 Construction of three-phase induction motor 4222.6 Principle of operation of squirrel cage type 4222.7 Operating characteristics of three-phase I.M. 4222.8 Common single-phase types 4222.9 Selection for specific application	413.3 423.1 4221.4 224.2 4221.6 4222.3 4221.4 224.2	Motor principle: $F = BIL$ Torque $\propto \phi I_a$ Energy conversion Regulation (C) $H.P. = \frac{TN}{5252}$ Rotating fields Electromagnetic induction Synchronization (C) $N_s = \frac{120f}{P}$ $\%\ Slip = \frac{(N_s - N_r)\,100}{N_s}$ Graphical representation of variables	Shunt, series and compound; armature torque Speed regulation Rate of rotation (N) Counter EMF Stator, rotor Synchronous speed, slip Squirrel cage induction motor Number of poles (P) N_s = Stator synchronous speed (RPM) N_r = Rotor speed (RPM) Split-phase motors Capacitor-start motors Shaded pole motors Series motors Centrifugal switch		
	422.3 Alternators	4223.1 Simple single-phase type with stationary field 4223.2 Waveform generated 4223.3 Alternator with rotating field 4223.4 Three-phase alternator: construction, connections 4223.5 Operating characteristics of commercial units	413.3 4114.3 411.4 414.2 4221.6 4221.4	Electromagnetic induction Faraday's Law: $E_{av} = \frac{\Delta\phi}{\Delta t}$ $e = E_m \sin\theta$ Bidirectional flow (C) $f = \frac{P.N.}{120}$ Excitation (C) Phase relationships Regulation (C) Synchronization (C)	Alternator Slip rings Sine waves, hertz Stator, rotor Salient pole Excitation 3-wire, 4-wire systems Wye, delta connections KVA Voltage regulation Synchronization		
42.3 Measurement *Estimated periods: 3T 3SA*	423.1 D'Arsonval galvanometer	4231.1 Construction and operation of basic instrument 4231.2 Applications: ammeter, voltmeter 4231.3 Sensitivity	4222.3 322.2 4122.2 444.1 444.2 3112.2 312.2 3231.4	Motor principle Torque $\propto \phi I_a$ Linearity Ohm's Law Sensitivity (C) Accuracy Range	Galvanometer Shunts, multipliers Range Sensitivity, ohms per volt Parallax Linear scale Accuracy, precision	**SHUNTS AND MULTIPLIERS (E)** To use shunts and multipliers to extend the range of ammeters and voltmeters, respectively. **WHEATSTONE BRIDGE (E)** To become familiar with the theory and operation of the Wheatstone bridge.	The D'Arsonval movement has, of course, very wide application. Some special types of galvanometers might be mentioned. The students must be able to connect and accurately read the instrument proficiently. They should appreciate that accuracy and precision are not synonymous.
	423.2 Electrical bridges	4232.1 Wheatstone bridge 4232.2 Potentiometers (O)	444.1 3413.1	Bridge configuration $R_x = \frac{R_1}{R_2} \times R_3$ Balanced conditions	Electrical bridge Balanced conditions, null		

UNIT: 4.3 Electronic Devices

Component	Sub-topic	Element	Cross-reference	Fundamentals	Technical Terms	Student Activity	Discussion
43.1 Electron emission *Estimated periods: 3T 5SA*	431.1 Vacuum diode	4311.1 Construction and function of each part 4311.2 Edison effect 4311.3 Plate characteristic curves	4112.3 2213.1 441.1 441.2 441.4 441.5 4312.2	Electron emission Energy conversion Law of Electrical Charges Graphical representation of variables Coulomb's Law Saturation (C) Unidirectional flow (C)	Thermionic emission Vacuum diode, cathode, filament, anode, plate Plate characteristic curves Linear, non-linear Saturation current	**DIODE PLATE CHARACTERISTICS (E)** To determine the nature of the plate characteristic curve of a vacuum diode. **TRIODE PLATE CHARACTERISTICS (E)** To determine the family of plate characteristic curves for a typical vacuum triode. **VACUUM TUBE MANUAL (X)** To gain familiarity with the information obtainable from a tube manual, including a comparison of the plate characteristic curves of triodes, tetrodes and pentodes.	The important ideas are listed in the "Fundamentals" column. The students should calculate the diode resistance from the plate curves. The explanation of the control grid action can be anticipated by the students if they know the Electrostatic Laws. Tube "constants" should not be introduced. The exercise with the tube manual might be done in the form of a classroom discussion with overhead projector and tube manuals at hand. Of course, a c.r.o. curve tracer would be ideal.
	431.2 Vacuum triode	4312.1 Construction and function of control grid 4312.2 Plate characteristic curves	4112.3 411.3 431.1 442.1 4311.3 442.4	Repeat those of 431.1 Biasing Electrostatic fields	Space charge Control grid, bias Cut-off voltage Triode plate characteristics		
	431.3 Vacuum pentode	4313.1 Construction and function of each part of pentode 4313.2 Advantages of pentode compared to triode 4313.3 Plate characteristics	4112.3 411.3 431.1 431.2 442.1 442.2	Negative resistance	Tetrode, pentode Screen grid, suppressor grid Negative resistance		
43.2 Solid state *Estimated periods: 6T 5SA*	432.1 Diodes	4321.1 Doped semiconductors 4321.2 P-N junction: construction and electrical properties 4321.3 Characteristic curves	412.1 1442.2 431.1 411.1 411.2 44.1 2213.1 4312.2	Crystalline material Effect of impurities on properties Biasing Unidirectional flow (C)	Crystal structure Semiconductors, doping P - material, N - material P-N junction Forward and reverse bias Breakdown voltage, Zener	**P-N JUNCTION CURVE (E)** To measure and plot the characteristic forward and reverse currents of a P-N junction diode. **JUNCTION TRANSISTOR (E)** To measure and plot the family of collectors curves of a PNP or NPN junction transistor. **FIELD EFFECT TRANSISTOR (A) (O)** To make a comparison of field effect transistors with vacuum triode and junction transistor.	This section emphasizes the transistor construction and operation in descriptive terms. The nature of a crystalline material and the effects of impurities determine transistor action. This should be clearly understood before quantitative considerations are introduced. Again, it is important that the students are able to interpret the curves which they obtain experimentally. The use of field effect transistors is increasing. However, the teacher may content himself with a table comparing the FET with other amplifying devices.
	432.2 Junction transistors	4322.1 Transistor construction 4322.2 Transistor action 4322.3 Characteristic curves	411.1 411.2 411.3 4312.2	Biasing Law of Electrical Charges Graphical representation of variables	PNP, NPN junction transistors Emitter, base, collector Bias current Heat sink Holes, majority and minority carriers		
	432.3 Field effect transistors (O)	4323.1 Comparison of operating characteristics of F.E.T. with vacuum tubes and conventional transistors 4323.2 Applications of F.E.T.	431.2 431.3 432.2	Operating parameters Noise	Parameters Signal to noise ratio		
43.3 Photoelectric effect (O) *Estimated periods: 1T 2SA*	433.1 Photoemissive cell	4331.1 Phenomenon of photoemission 4331.2 Spectral response 4331.3 Commercial types and applications	4311.1 3142.3	Electron emission Selectivity (C) Energy conversion	Photoemission Photoemissive cell Photomultiplier Secondary emission Spectral response	**PHOTOELECTRIC EFFECTS (E)** To examine the operation of: • A photoemissive cell. • A photovoltaic cell. • A photoconductive cell.	This is an optional section, and yet photoelectric effects are important and interesting. Time does not allow a detailed study of the phenomena. This could be assigned as a technical assignment.
	433.2 Photovoltaic cell	4332.1 Phenomenon of EMF generation by light 4332.2 Spectral response 4332.3 Commercial types and applications	4114.3	Photoelectric effects Property changes due to environment	Photovoltaic cell		
	433.3 Photoconductive cell	4333.1 Phenomenon of resistance change with light 4333.2 Spectral response 4333.3 Commercial types and applications	412.1	Non-linearity (C)	Photoconductive cell Non-linear devices		

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DIVISION FOUR: ELECTRICITY

UNIT: 4.4 Circuits and Systems

Topic	Sub-topic	Element	Cross-reference	Fundamentals	Technical Terms	Student Activity	Discussion
44.1 Rectifying circuits *Estimated periods: 5T 5SA*	**441.1 Half wave**	4411.1 Basic circuit: a.c. to d.c. 4411.2 Rectifier ratings	431.1 432.1	Unidirectional flow (C) Rectification	Half wave rectifier Peak inverse voltage Ripple, B plus and minus Power transformer Full wave rectifier	**BASIC POWER SUPPLY (E)** To connect and study the operation of: • A half wave supply without filter. • A full wave supply without, and with, smoothing filter. **SILICON CONTROLLED RECTIFIER (E)** To study the output waveforms from a silicon controlled rectifier supply.	Because the conversion of a.c. to d.c. is common in electrical apparatus, sufficient time must be given to its study. The diodes may be vacuum or solid state, or both. Safety considerations are vital when working with electronic power supplies. The choke input filter can be analyzed very nicely when considered as an a.c. voltage divider. Both Topics 441.4 and 441.5 are marked optional because the teacher may wish to devote all ten periods to a careful treatment of basic power supplies.
	441.2 Full wave	4412.1 Transformer-type circuit, without filter 4412.2 Operation	441.1	Frequency doubler	Power transformer Full wave rectifier		
	441.3 Smoothing filter networks	4413.1 Effect on ripple of L. and C. 4413.2 Analysis of L.C. filter 4413.3 Pi filters 4413.4 Complete power supply circuit	414.5 414.6 414.7 421.2 421.3 2512.3 443.2 2251.1	Filtering (C) Energy storage $\% \text{ ripple} = \frac{E_{ripple}}{E_{dc}} \times 100$ Regulation (C)	Choke input, capacitor input Pi filters Regulation Bleeder		
	441.4 Silicon controlled rectifier (O)	4414.1 Construction 4414.2 Operation 4414.3 Applications	432.1 221.3 3312.1	Switching Phase relationships	Gate, trigger action Silicon controlled rectifier Phase shift		
	441.5 Voltage doublers (O)	4415.1 Cascade circuit 4415.2 Operation	421.3 441.1	Cascading Energy storage	Voltage doubler Transformerless		
44.2 Amplifying circuits *Estimated periods: 10T 12SA*	**442.1 Voltage amplifiers**	4421.1 Circuit configurations 4421.2 Amplifying action of: • Grounded cathode circuit • Common emitter circuit 4421.3 Graphical analysis: load lines, classes of operation 4421.4 Methods of biasing 4421.5 Methods of coupling	431.2 431.3 432.2 2413.1 3212.1 3211.1 3231.4 4312.2 4322.3 4312.1 4322.2 422.1 4147.4 414.9	Amplification (C) Graphical representation of variables Load lines Distortion Biasing Coupling Time constant	Voltage amplifiers, circuit configuration Plate load Signal voltage Phase inversion Load lines, operating point Classes of operation Gain Distortion, fidelity Fixed bias, self-bias Bias stabilization, thermal runaway Coupling: direct, R-C, transformer Frequency response	**TRIODE AMPLIFIER (E)** • Analysis of electrical conditions in an operational amplifier stage. • Measurement of stage gain. **SIMPLE AMPLIFIER SYSTEM (E)** • To use graphical analysis to design a simple triode amplifier. • Confirm design by measurements. **POWER AMPLIFIER (E)** • To measure power gain of: — singe-ended power amplifier. — push-pull power amplifier. **FEEDBACK (E)** To note the effects on amplifier performance of: • Negative feedback. • Positive feedback. **RADIO FREQUENCY OSCILLATOR (E)** To study the operation of an R.F. oscillator in which the feedback and operating frequency are variable.	The experiments in this section may be done with vacuum or transistor devices, or both. Amplification is, of course, a concept which has broad application in mechanical, electrical, magnetic and fluid amplifiers. As in many other parts of this course, it is more important to convey the meaning of the concept, e.g. amplification, feedback, than it is to familiarize the student with many examples. The concepts have broad applications whereas the details of particular circuits do not. This course should provide a formative experience, not merely informative. The positive feedback should be sufficient to cause oscillation in order for the student to understand what an electronic oscillator is. A block diagram of a complete receiver and/or transmitter would help the student appreciate the application of the many components and circuits that he has been studying.
	442.2 Power amplifiers	4422.1 Comparison of voltage and power amplifiers 4422.2 Impedance matching 4422.3 Push-pull configuration 4422.4 Complete amplifier system: applications	442.1 422.1 4147.1	$\text{Power gain} = 10 \log \frac{P_1}{P_2}$ $\text{Impedance matching: } \frac{Z_p}{Z_s} = \left(\frac{T_p}{T_s}\right)^2$ Push-pull action	Power amplifier Plate and screen dissipation Decibels Impedance matching Push-pull Distortion		
	442.3 Feedback	4423.1 Definition: positive and negative 4423.2 Effects of negative feedback 4423.3 Effects of positive feedback	442.4 443.2 443.3 331.1 2253.2	Feedback (C) Oscillation	Voltage feedback Positive and negative FB Oscillation Damping		
	442.4 Oscillators	4421.1 Necessary conditions for oscillation 4421.2 Basic circuit configurations 4421.3 Applications	442.3 414.7 414.9 444.2 444.3	Oscillation (C) Damping (C) Resonance (C) Energy storage	Oscillators, A.F. and R.F. Damping Resonance Armstrong, Hartley, R-C types Tank circuit Grid leak bias, time constant		
44.3 Control circuits (0) *Estimated periods: 3T 3SA*	**443.1 Photoelectric**	4431.1 Typical application 4431.2 Analysis of circuit operation of one application	411.4 43.3	Photoelectric effect Systems approach	Control system	**CONTROL SYSTEM ANALYSIS (E)** To study the operation of a complete control system.	The suggestion here is that only one of these control systems be studied in the classroom. This does not preclude the possibility of student assignments relating to control circuits. The concept of a closed loop system is particularly valuable.
	443.2 Voltage regulation	4432.1 Closed loop systems 4432.2 Analysis of circuit operation of one application	331.1 442.3	Regulation (C) Feedback (C) Closed loop system	Voltage regulation Closed loop system Feedback		
	443.3 Motor speed	4433.1 Closed loop systems 4433.2 Analysis of circuit operation of one application	331.1 442.3 4222.4 4222.7				
44.4 Test equipment systems *Estimated periods: 4T 6SA*	**444.1 Electronic voltmeter**	4441. 1 Block diagram 4441.2 Analysis of circuit operation 4441.3 Advantages and disadvantages compared to V-O-M meter	4232.1 423.1	Bridge configuration Input impedance Sensitivity (C) Range	Input impedance Electronic voltmeter Sensitivity, range Frequency response	**ELECTRONIC VOLTMETER (E)** To develop proficiency in the use of an electronic voltmeter. **CATHODE RAY OSCILLOSCOPE (E)** To develop proficiency in the use of the cathode ray oscilloscope. **SIGNAL GENERATORS (E)** To develop proficiency in the use of R.F. and A.F. signal generators.	The proficient use of test instruments is essential if many of the experiments of this course are to be carried out efficiently. It would be advisable to introduce the use and proper operation of the voltmeter and the C.R.O. at an early stage: comprehension of their internal operation could come later. The cathode ray oscilloscope offers an excellent natural apex of this course of study. It incorporates nearly every section of Division Four except those dealing with machines.
	444.2 Cathode ray oscilloscope	4442.1 Block diagram 4442.2 Construction and operation of cathode ray tube 4442.3 Measurement capabilities of C.R.O.	44.1 44.2 414.2 414.3 3112.2 3212.1 3213.2 3231.2 3231.4	Time base (C) Sensitivity (C) Luminescence: energy conversion Electrostatic Laws Waveform analysis Linearity Synchronization (C)	Luminescence Electrostatic deflection Electromagnetic deflection Time base, sweep voltage and frequency Deflection sensitivity Sawtooth waveform Linearity Synchronizing		
	444.3 Signal generator (O)	4443.1 Block diagram of R.F. type 4443.2 Block diagram of A.F. type 4443.3 Uses of signal generators	442.4 414.2 414.3	Oscillation (C) Feedback (C) Modulation (C)	Oscillators: R.F. and A.F. Amplitude and frequency modulation Signal injection and tracing Alignment		